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Perceptual Methods for Environmental Assessment: Odour and Landfill

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Abstract

This thesis investigates the phenomenon of environmental annoyance from waste management, specifically landfill odours. The research study identifies the scope and significance of parameters that influence the extent of impact and includes these in a framework that can be used to influence the design and development of a population response model for odours.

The research design considers the physiological, lifestyle and location factors that influence exposure and response to landfill odour and addresses three research objectives:

- To produce a framework within which a community based population response model could be developed.
- Determine and demonstrate the variability of response within a population exposed to landfill odour.
- To determine and demonstrate how spatial and temporal factors also contribute to the differential exposure and response of individuals to odour pollution.

The research activity involved the design and implementation of an odour monitoring panel. Volunteers were recruited in the vicinity of two landfill sites where they monitored daily for odours for three months. This programme provided information on their routine activities and exposure to odour at the time.

The thesis concludes by noting the following:

- Location and climatic factors may generate more variability (at this scale of sample) than interpersonal differences.
- The results from laboratory experiments examining hedonic properties were not repeated in the external environment.
- The response levels between males and females were inconsistent with current knowledge and research assessing gender differences in the ability to detect odours.

Additionally, the research demonstrates how data on the detection of odour in communities could be included in research activity that links olfactometry and the experience of odour in the environment.

Acknowledgments

Very special thanks to my supervisors, Roger Seaton and Phil Longhurst, without whom the project would not have been completed. Their sympathy and encouragement through some particularly trying times, along with their academic support, was very much appreciated. Thanks also to the other members of staff, particularly Maureen Mahoney, for keeping the 'form-filling' and me organised!

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I won't mention them individually in case I miss someone, but a big thank you to all my fellow students at Ecotech, for their support, comradeship and their being a bottomless source of commiseration!

I would also like to thank the volunteer monitors for their commitment and enthusiasm for the project and without whom this would not have been possible.

Thanks too, to Chris and Nick Goddard for their input into the thesis. I think that being made to read this masterpiece deserves a big box of chocolates!

Finally, thanks to my dear friends and family, who have been a source of much support and belief in me when I had none myself. Their support was much appreciated.

Dedication

To John, Becky and Hannah
Sine qua non

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Chapter 1

Public Perception and the Strategic Management of Landfill Odour

1.1 Landfill Odour Pollution

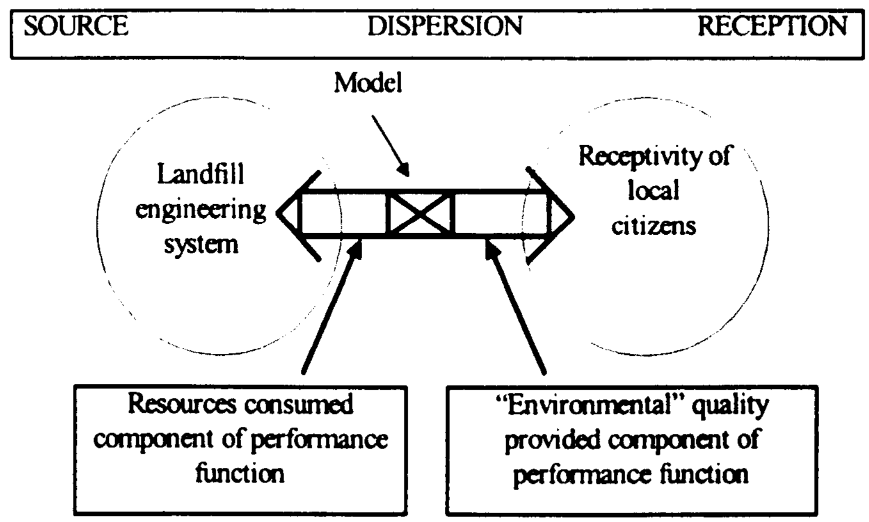
In the UK, approximately 371 million tonnes of waste is generated each year (NASCA 1996) and of this, 86% is disposed of to land at designated sites. This disposal process is referred to as landfilling. Until the 1930s, this process was largely uncontrolled leading to unsightly and inadequately managed fills (Baker et al. 1984). This gave rise to, what Campbell (1992) referred to as a public attitude of a landfill being a "'dump' or 'tip'". Today, landfills are subject to strict legislation demanding a high level of understanding about landfill processes and professionalism on the part of operators (Campbell 1992). Landfill sites are usually disused mineral extraction sites, although other locations, such as salt marshes and valleys have been used in the past (Baker et al. 1984). Organic waste materials will decompose over time, often in the region of decades, to stable material (Baker et al 1984). However, it is during the intermediate stages of decomposition between collection of waste and its stabilisation, that release of odour causing chemicals takes place. This release, which can occur, not only at landfill sites, but waste treatment stations and transfer stations, can and does generate nuisance in surrounding communities.

Landfill sites can have many other forms of impact on the surrounding environment including local communities. The landfill can be the emission point of gases and leachates (fluids evolved during waste breakdown) which can affect the local area, for example through contamination of soils and adversely affecting vegetation. The effects also include noise, traffic, windborne litter, vermin and aesthetic impacts.

There are attempts made to control odours, such as use of cover materials or masking agents (see Section 4.4), but it is not clear how successful these strategies are. Odour production and release are dependent on many factors, such as the landfill itself (processes and conditions found within the waste material) and management practised by the site operators. Climate has a major impact on processes operating within the landfill site, and on management and emission of odour-causing compounds. There may be more than one emission point on-site, emission rates are unknown, and the odour may vary due to the various potentially odorous compounds that may be emitted in different combinations. This is a challenging situation for operators (see Section 4.4).

1.2 The Research background

Landfill sites have been described by Longhurst and Seaton (1999) as "rapidly changing, biologically active, engineered structures where attempts to ensure the reliability of operational performance can pose a significant management challenge". They developed a conceptual model of the interaction between the engineering issues at a landfill site and the communities affected by landfill odour emissions. This is shown in Figure 1.1.



(source: Longhurst and Seaton 1999)

Figure 1.1: The interaction of the landfill engineering system and the social system

It can be seen that there are two elements present, the landfill engineering system and the receptivity of local citizens. They are linked by the process of transportation or dispersion of odour emitted by the landfill site to locations where the odour can be detected by local people. This link is far more complex than this simple statement may suggest. The odiferous gases emitted by landfill sites are the product of a variety of processes operating within the site. These gases are released into the atmosphere, where they can be transported some distance from the landfill. Whilst undergoing this transportation process, the gases may undergo dilution or physico-chemical change, due to, for example interaction with other atmospheric components or sunlight, deposition or decomposition (see Section 4.4). The product of these processes, potentially altered odiferous gases is delivered to individuals, who may or may not be able to detect and respond to them (see Chapter 2, Sections 3.2 and 3.3, Section 4.4). This detection and response is referred to as "receptivity" by Longhurst and Seaton (ibid). This term was applied initially to the response of industrial organisations to innovation and to "address the social and organisational perspectives of technology impact" (Longhurst and Seaton ibid). The authors go on to say that the term has been applied to other phenomena, and now to landfill management and impact. The model shown in Figure 1.1 was extended by Longhurst and Seaton (ibid) into the conceptual model shown in Figure 1.2, which takes into account the social and economic trade-offs between management of odour on landfill sites and the responses of affected communities and regulatory bodies and other public agencies. Figure 1.2 overleaf presents the whole model as developed by Longhurst and Seaton. This thesis is located within this wider model and the concept of receptivity. The specific area of interest of this thesis is the shaded area at the bottom and right-hand side of the figure. The shaded area represents the environment of the research and the blocked in and bold boxes represent the specific area of the research.

The area of interest in this thesis is therefore about consequences of the "delivery" of odour to specific areas and the extent of the impact it has. This impact is dependent on time, duration and the intensity of the odour at locations outside the landfill site. It is also dependent on the spatial and temporal distribution of people surrounding the site, and, importantly, their varying sensitivities to odiferous gases. It will be shown in this thesis that odour impact from landfills is dependent on spatial and temporal factors (see Chapter 3) and the diverse attributes of individuals (see Chapter 2). It will be proposed that the interrelationship of landfill odours and individuals, and the impact they have on each other could be estimated or predicted through the use of a population response model. By using such a model, it should be possible to gauge the effects on levels of annoyance and loss of amenity by changes in landfill management and operations. Or conversely, estimate the impact on landfill management by changes in levels of detection of odour caused by changes in the population surrounding the landfill site. Firstly, in this Chapter, there will be a review of these factors before they are examined in further detail in Chapters 2 and 3.

1.3 Transportation and Transformation

A landfill site can be regarded as the source of the pollutant, in this case odour. It is the first stage of a three-stage process leading to response to odours by individuals and communities (Longhurst and Lemon 1996, Longhurst and Seaton 1999). This three-stage process is shown in Figure 1.3.

The first stage, related to the source and emission of odour, falls almost completely outside this thesis. It is of interest, however, as it is the source of the problem. The second stage of the process is the attenuation or dispersion stage. This also falls outside the immediate area of the thesis, but is important, as it is the means through which the problem of odour pollution occurs. This phenomenon between the source and its reception is the transportation of the odour plume including its possible transformation due to physical and chemical processes. In the case of odour, whilst the compounds travel through the atmosphere, they may decompose, undergo reaction with other atmospheric components or become diluted with non-odorous air. Atlas et al. (1993) relate how organic chemicals, which may include odour-causing compounds present in the atmosphere, can be transported and diluted. They also highlight the reactions such chemicals may undergo. For example, they may react to form more stable species, oxidise to form more soluble compounds and be removed by precipitation, undergo photolysis or deposition. They state how the fate of organic chemicals can be dictated by levels of sunshine, the presence of oxidising agents and the time of day. This results in the odour emitted from the landfill site potentially changing as it travels through the air before it reaches a recipient. Studies are in

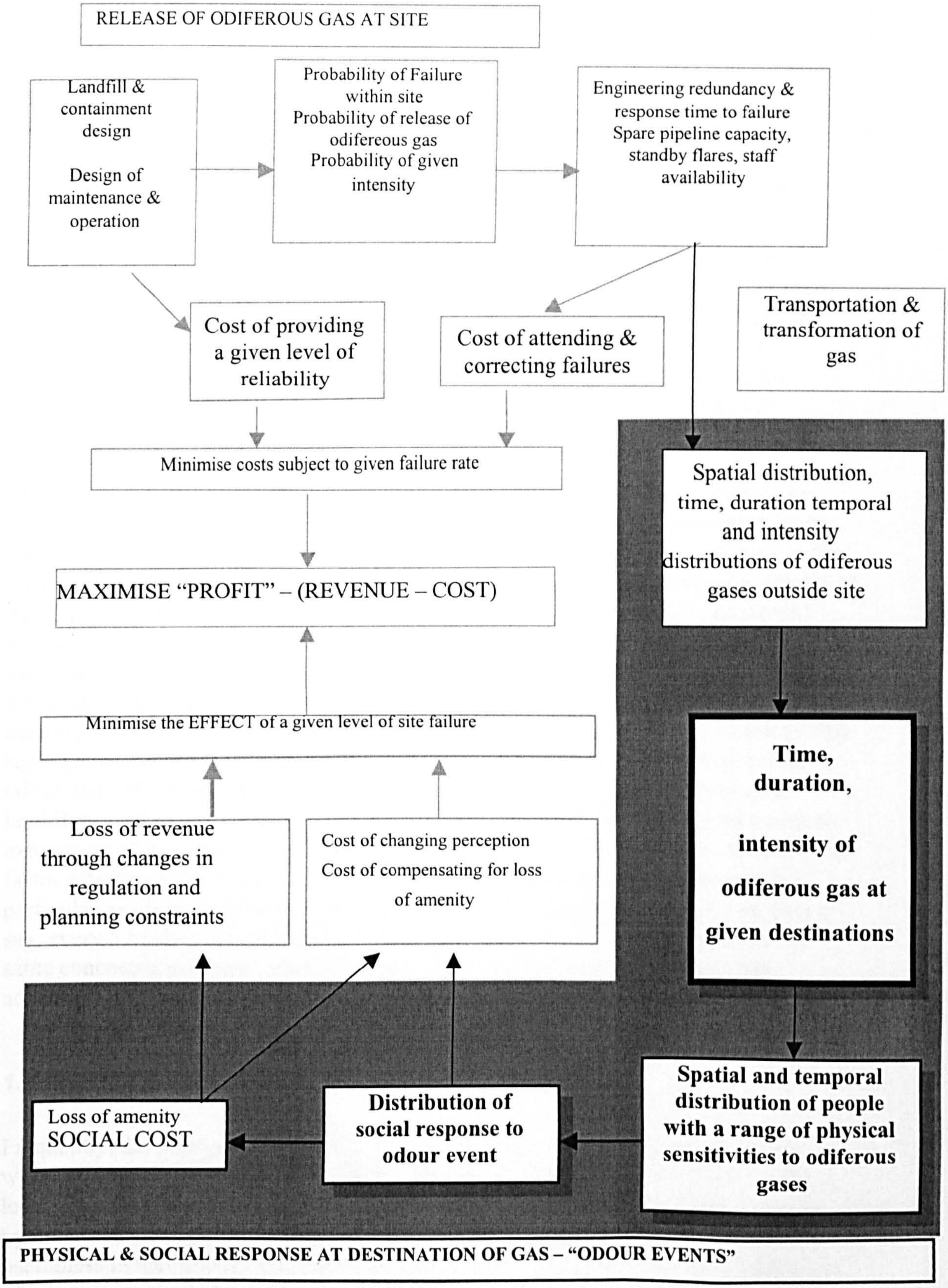


Figure 1.2: The adapted model from Longhurst and Seaton (1999) highlighting the research area of this thesis

Source → Attenuation/ → Receptivity
Dispersion

Figure 1.3: The three-stage process of environmental pollution impact

progress to understand further the behaviour of atmospheric contaminants, but the complete picture is unlikely to be obtained in the near future due to their complexity (Duce et al. 1983, Atlas et al. 1993). Attempts have also been made to simulate the dispersion of pollutants by mathematical models. These are used to assess the movement of pollutants through the atmosphere and to provide estimates of the concentration of the pollutant at selected points away from its source (see, for example Baker and MacKay 1985; Zeiss and Attwater1993).

The final stage of the process is that of receptivity, where the odour is detected by humans, generating a response. This is the area in which this thesis is located. There are varying levels of response due to a range of factors not just those operating at the source and during dispersion, but "human" factors. These are the personal attributes of individuals found in the community. These include their physiology, lifestyle and activities, and attitude to the odour source. Odour perception may lead to the individual undertaking a variety of avoidance activities. These may include coping or avoiding strategies such as going indoors or closing windows. They perceive a loss of amenity, or others may perceive this loss as such e.g. a blighted area. Furuseth (1990) reported in his study that respondents to his survey reported problems with noise, odour and reduced property values. They may respond by making complaints to landfill operators or to local authorities. The individual will have their own personal experience of frequency, duration and intensity of environmental odour. An additional factor affecting odour exposure will be the length of time an odour is present at a particular location. As Diaper (1987) questions "Is a 5 second exposure to an odour, say, every 5 minutes as annoying as a 1 second exposure to the same odour at the same concentration every minute?". These qualitative aspects are perhaps best addressed by asking individuals potentially affected by odour pollution.

1.4 Social Surveys versus Physical Measurement

Frequently, the problem of the issue of odour pollution only comes to light in the wake of complaints being made, either to landfill operators or to other bodies such as local councils. They are commonly used to define the extent of the nuisance generated by odour. However, it is argued in this thesis that complaints have only limited usefulness in identifying the extent of odour nuisance and that in fact the distribution of odour impact may be quite different to what is implied by complaints. Attempts to ascertain the nature or extent of odour pollution impact is to use instrument-based methods, such as GC-MS (Gas Chromatography and Mass Spectroscopy) or dispersion modelling, or use of "sensory" methods using complaints, social surveys or monitoring panels of volunteers. These methods are reviewed in far greater detail in

Sections 3.2 and 3.3. Each approach has its advantages and limitations. In odour impact studies usually only one type of technique is used, which can lead to an incomplete picture of impact being produced. It is seldom that more than one technique is used in a study, however advantageous that may be. Bruvold et al. (1983) used social surveys and measurement of odiferous gases in ambient air, but such a practice to combine sensory and instrument-based methods is unusual. Van Harreveld (1997) conducted a survey of potential odour impact using only a dispersion model. This practice is far more the norm. An appropriate method to assess odour impact is to ask the affected communities what their experience of odour is, but this is seldom done. This could be a result of the difficulty of modelling the extent of odour impact from a community-based perspective.

Within this thesis, the author proposes that, in order to understand fully the nature of the impact of a pollutant on an individual or community, it is necessary to examine the response to such levels of pollutant exposure by surveying the community. It should be noted that the impact would vary, not only due to environmental factors, but also to personal attributes and activities of individuals in these communities. This study is designed with the intention of attempting to understand how personal factors affect exposure and an individual's response to pollution and gain greater insight into community impact. It will then go on to develop an approach or method by which population response to odour can be modelled. The data would be derived from the community and based on response of the individual to odours. This is in contrast to the quantitative data associated with measurement at the odour source, such as concentrations of odour causing compounds, or the identification of odour causing compounds and measurement of their concentrations in the laboratory. The method for this research is presented in the next section.

1.5 The Research Method

As shown by Longhurst and Seaton, there is a need for a defined method for odour impact assessment that is based not solely on emission rates at source and concentration at distance, which would be undertaken using physical measurement. The response at the point of impact, namely a settlement or individuals within that community should also be included in the assessment. However, assessment of this response is difficult to undertake, due to the differing attributes of individuals. These attributes include physiological factors and lifestyle, as well as their location. It is proposed in this thesis that a population response model can be developed in order to assess community exposure and response. Development of such a model would refer to, and include, knowledge and methods from several areas.

Firstly, knowledge of the physical environment, including the odour source. Secondly, understanding of instrument based and sensory (human) methods used to assess odour and pollution it may cause. Finally, an understanding of exposure and responses to odour pollution, including factors affecting exposure and response. By pulling together these diverse strands, scientific and social research can be linked to produce a population response model. These linkages are shown in Figure 1.4. Input from the "Environment including the odour source" would include an understanding of the processes associated with the landfill and monitoring and measurement of odour at the source and in the environment. It also includes an understanding transportation and transformation of odours in the environment. This strand sits outside the thesis per se, but provides the background in which odour pollution occurs.

The second strand, "techniques for pollution assessment", includes the use of different techniques for odour pollution measurement or estimation of impact. This area falls partially within the area of the thesis. Olfactometry, the testing of the individual's sense of smell and qualities of odour (see Section 3.2) falls within the area of this thesis and so falls partially in the shaded area in the diagram. The third strand, "Pollution impact and human exposure and response" relates directly to this thesis- hence the modelling response box falls within the thesis area. By its very nature, such research is interdisciplinary in nature, drawing as it does from diverse areas of research. Such a model can be used in tandem with measurements made at source and dispersion modelling to ascertain odour pollution impact at all stages from production and emission to exposure and response. This practice of combining community response and measurement and estimation of impact using dispersion models could be referred to as an interdisciplinary method.

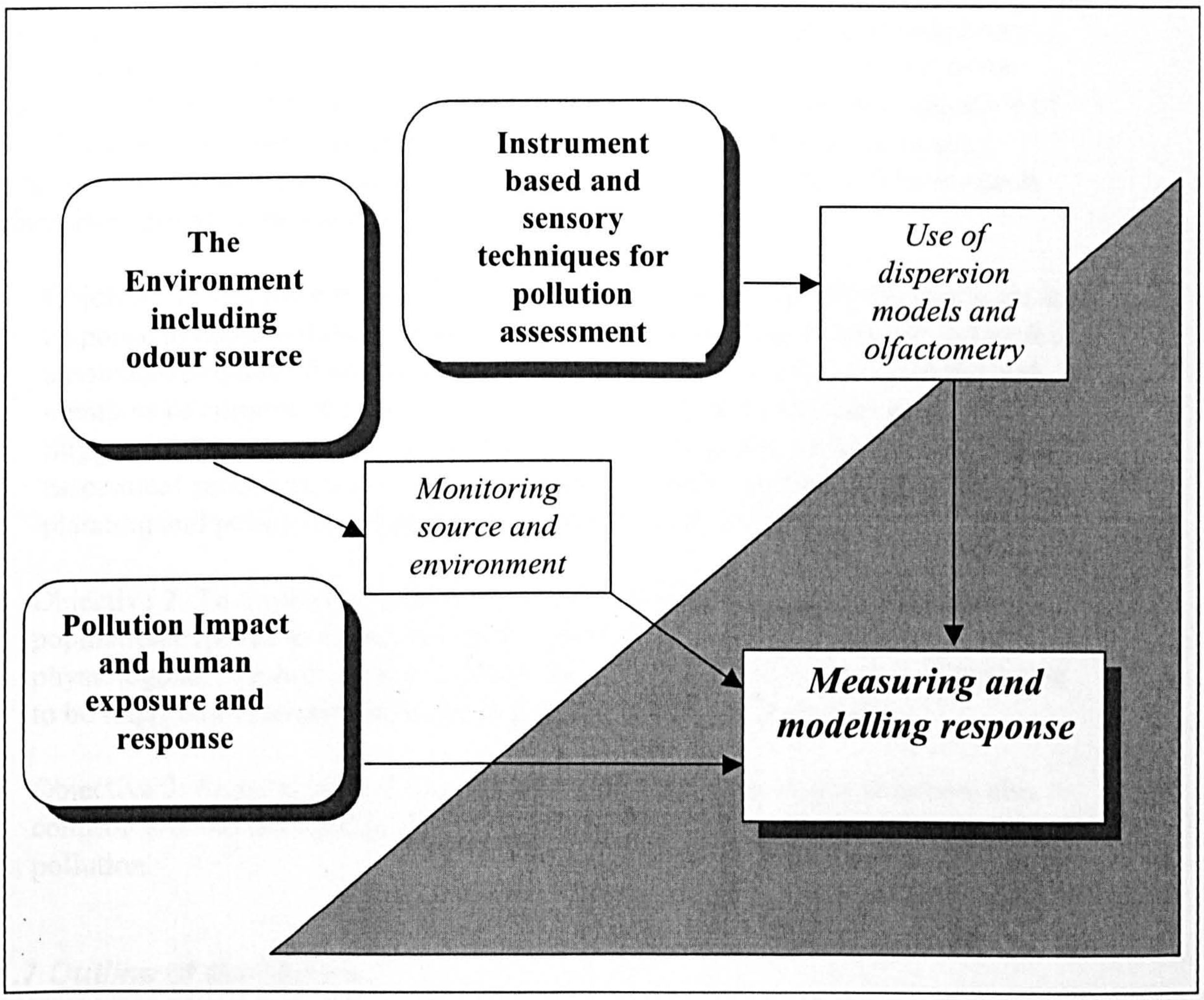


Figure 1.4: The three major areas relevant to an interdisciplinary method of odour assessment and how they are linked to this thesis

The recognition and use of such perception-based information has been recognised in other areas of research. Hadfield (1997), for instance, examined such information in her work on asthma and perception of air quality. This work was conducted in Bedfordshire and examined a number of sources of air pollution, primarily that arising from traffic pollution.

1.6 The Research question and objectives

The research question within which this research is placed is

To what extent do physiological, lifestyle and locational factors influence exposure and response to landfill odour?

In addressing this question, the research activity is concerned with identifying factors or attributes related to individuals that could be included in the development of a framework on which a population response model could be based. Such a model could be used as part of an interdisciplinary method. This method would combine both the quantitative and qualitative approaches of odour measurement and movement with the experience of odour pollution amongst individuals. Only such an interdisciplinary method can clarify the complex relationship between the source, the odour in the environment and the response provoked in the population. The ultimate objective of this thesis is to take steps to identify parameters affecting odour exposure and response and propose a framework for a potential model of response. The research objectives arising from this are:

- Objective 1: The main objective is to identify attributes affecting the exposure and response to odour within a community. These attributes could then be included in a potential response framework that could be used to identify communities and members of communities at more or less risk of exposure and impact to odour. Suggestions are made on how this model, when integrated within environmental assessment procedure could be used as a tool to assist landfill management, planning and policy regarding environmental impact and nuisance.

- Objective 2: To measure and demonstrate the variability of response within a population exposed to odour. It will be shown that variability arises from physiological, psychological and behavioural factors. These factors will be shown to be important determinants in the individual's experience of odour.

- Objective 3: To measure and demonstrate how temporal and spatial factors also contribute to the differential exposure and response of individuals to odour pollution.

1.7 Outline of the Thesis

One of the main activities in this thesis is that of measuring the variability in detection and response to odour found in a population that is exposed to landfill odour. Using this data, attributes affecting exposure and response to odour are identified. A possible method on which a population response framework could be developed and utilised is illustrated. The thesis proposes an interdisciplinary method for odour impact assessment, which would utilise emissions data obtained from landfill sites, dispersion modelling and population data on exposure to odour. Figure 1.5 presents an outline of the structure of this document.

- Chapter 2 provides a review of what is known of the factors that are known to affect the sense of smell in the individual. This includes not only examining factors, such as health and age, but also how attitude and experience may affect perception. Two arguments will be proposed.
  Firstly, that odour pollution is more complex than simply the presence of odour and people at the same location at the same time.
  Secondly, that what an individual perceives is a product of the interaction of physical, psychological and behavioural phenomena, not solely a product of concentration of a particular chemical at a particular location.

- Chapter 3 presents information on several key areas of odour research. These are terminology, and instrument and sensory ('human') techniques used in odour assessment. The uses of monitoring panels are examined in detail, as a form of panel was used for the research.

- Chapter 4 develops the research issue, questions and objectives. This includes the identification of the two groups of key concepts in the research. These are
  a) environmental factors, namely physical (related to the source), temporal and spatial.
  b) factors relating to the population experiencing odour and include physiological, psychological and lifestyle factors.
  The choice of research of techniques is discussed. This includes a reiteration of techniques available and arguments for the use of a monitoring panel. The case study, landfill odour pollution, is presented. The reasoning behind the decision not to use an atmospheric dispersion model is also given. The design of the research activity is further detailed.

- Chapter 5 introduces the context of the research activity, namely landfill odour in the Marston Vale area of Bedfordshire. It identifies previous research in the locality and how information from this earlier work generated the research questions and activities for this thesis. The questions arising from the earlier research led to the production of a conceptual device, an 'odour perception tree'. This was used to identify the processes influencing whether a monitor on a panel reported an odour or not. On the basis of the research questions and the monitoring tree, the details of the research design are provided.

- Chapter 6 provides information on the design and use of the odour-monitoring panel. This includes how monitors were selected, their olfactory ability tested, instructed on what monitoring involved and how they monitored. The way the results from individual monitors were to be broken down for assessment is

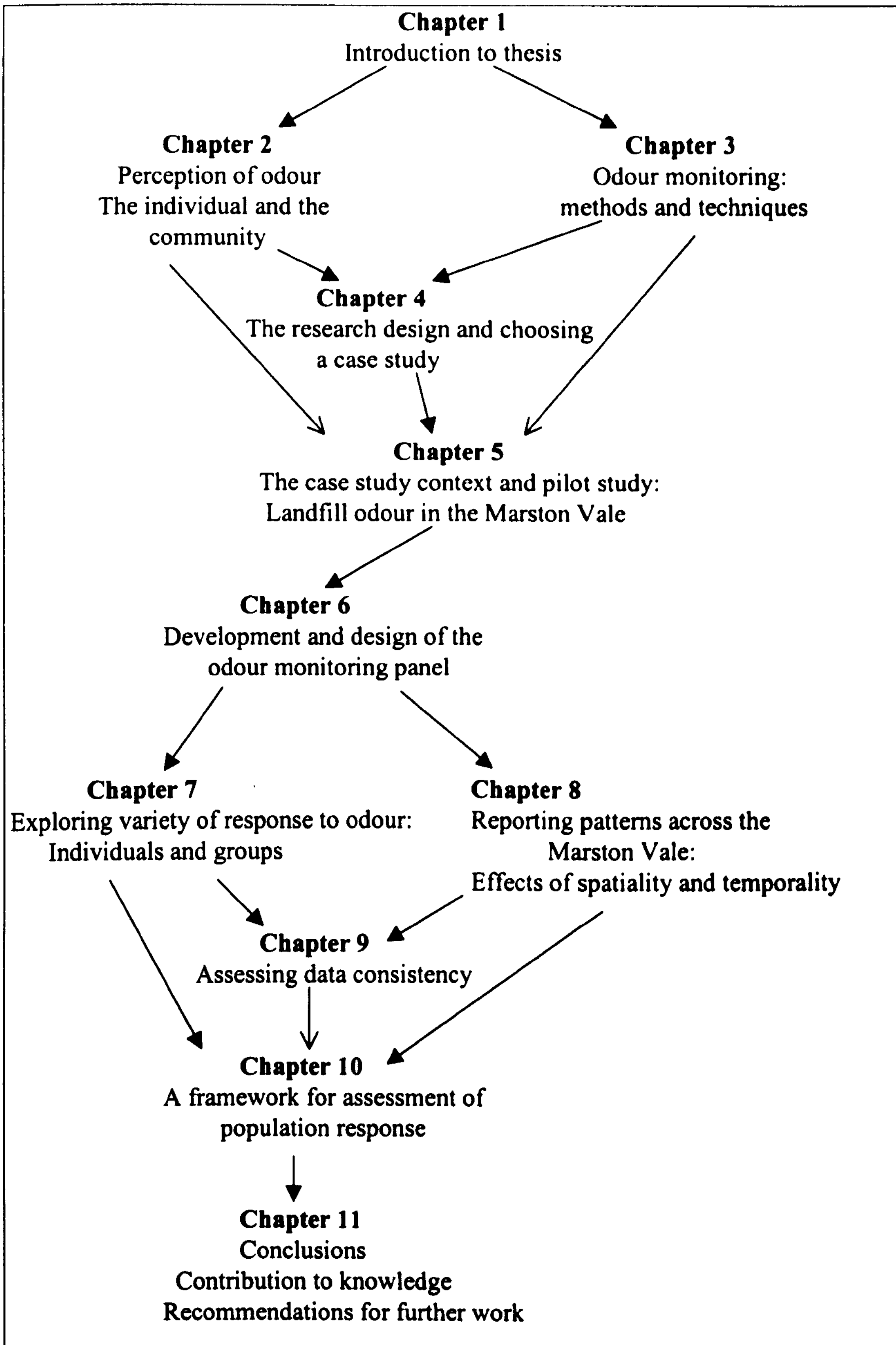


Figure 1.5: Outline of the thesis

presented. Validation of monitors' reports is also examined. One method used was comparing the cloud and visibility conditions recorded by monitors when they made their reports to other reports made at the same time. Comparison of monitors' reports with wind direction and wind speed as a means of attempting to assess the accuracy of reports is also discussed.

- Chapter 7 relates the results arising from analysis of the reports submitted by the monitor panel introduced for this research. The results will be examined from the perspective of individual monitors and groups of monitors with different attributes. This includes discussion of reporting intensity values and inclusion of appropriate statistical tests. It will be demonstrated that detection and response of odour is a product of the interaction of the key components first identified in Chapter 4 (research objective 2).

- Chapter 8 examines the variability in detection of odour found in settlements across the Marston Vale (research objective 3).

- Chapter 9 relates the efforts made to assess the consistency of monitors' reports. This was undertaken in a number of ways. By examining the reporting patterns of long-term and new monitors; examination of monitors' absence levels; results of a post-monitoring questionnaire; relationship of complaints and reports; weather descriptions made by monitors, and comparing reports with wind speed and direction.

- Chapter 10 describes a possible population response framework could be developed based on the results related in Chapters 7 and 8. It will be indicated how levels of exposure could be estimated or predicted for different types of individual by use of such a framework (research objective 1).

- Chapter 11 commences by re-examining the research questions and objectives. The procedures used in odour impact assessment studies are reviewed and discussion will then move on to examine an interdisciplinary method of odour assessment and how it could be implemented. The chapter concludes with a summary of the location of this research to other areas and recommendations for further study.

Chapter 2

Perception of odour: the individual and the community

2.1 Introduction

The levels of exposure to odour that an individual experiences, their ability to detect odour and their response to it may vary greatly. This variation may arise due to the odour's properties, such as its concentration, its detection threshold and its aesthetic or hedonic properties. An odour's detection threshold is the boundary on the physical concentration scale between the values where the odour is detectable or is not detectable (Engen 1982) (see 3.2.2). Odour aesthetics or hedonics refer to the odour's qualities or pleasantness or unpleasantness perceived by an individual. This can be, as Engen (ibid) suggests, a difficult area to assess, as individuals can vary in their preferences relating to odours, but it is important in the area of odour nuisance (see 3.2.3). However, the attributes of each individual may also affect exposure levels and annoyance caused. These attributes can be divided into three distinct groups. These are *physiological* attributes, that is the nature of the individual's sense of smell, their *psychological* attributes, which includes their opinion of the source and how much annoyance is experienced and their *lifestyle* and how it affects their exposure to odour. Each individual may also experience external influences that may influence their response. These attributes are examined in this chapter.

When an odour is present, any exposed individual must be able to sense or smell the odour in order to respond to it. It will be shown in Section 2.2 that there are a number of factors that may affect the individual's sense of smell. These include factors such as aging, health and exposure to dusts and chemicals. These factors operate on the individual's sense of smell, which in itself is unique, being inherited from parents and grandparents. All these components can be referred to, as above, as physiological components. As different individuals may have markedly different olfactory abilities, their ability to detect and respond to odours will also vary. What annoys one person so greatly that they are motivated to complain, may not be detectable to their neighbour. The sense of smell forms the first part of the sequence leading to detection and response to odour.

However, the ability to detect an odour is not the only factor to consider when attempting to study odour impact. Odour perception has a psychological component in that it can generate an emotional response. This makes it a unique air pollutant. Engen (1982) describes such a response recounted in a James Herriot novel. Herriot left his new wife to join the RAF during World War II, which was a painful experience. His wife had packed his bag, including a famous brand of soap. He used that soap on his first night away. He wrote later "I have never been able to use that soap since. Scents are too evocative and the merest whiff jerks me back to that night away from my wife, and the empty feeling I had then." This is a classic response to odour. Not merely is response a case of detecting an odour, it is also a value laden one. There will be a psychological response as well as a physiological one. This part of the overall response will be based on experience of the odour, which would include, for example, the frame of mind of the individual and their opinion of the odour source. The psychological factors to response will be examined in Section 2.3.

Also discussed in Sections 2.2 and 2.3, is the other major component of response to odour and that is the lifestyle of the individual. Lifestyle will dictate how frequently and when they will be exposed to odour. For example, an individual out of doors frequently may experience greater levels of exposure than someone indoors (see Section 2.2). This would contribute to their experience of the odour and their attitude to it and its source.

All these factors, physiology, psychology and lifestyle, form the background to the ability to sense and respond to odours. It will be seen from the discussion in the sections below, that these factors can vary between individuals and therefore the experience of odour between individuals in the same community can also vary. It will become apparent that the assumption of a community's response to odour pollution as the same is questionable.

2.2 Physical factors affecting odour response in the individual

The physical factors affecting an individual's sense of smell are examined in some detail in this section. These factors are summarised in Table 2.1. The table illustrates, firstly there are a number of factors which affect olfaction, and secondly, that these factors can vary in their effect, for example affecting the ability to discriminate between different odours or loss of olfactory ability (anosmia). The section commences with a brief summary of the sense of smell in humans.

2.2.1 The sense of smell in humans

What is referred to as 'the sense of smell' is in fact made up of two components. These are olfaction and sensory irritation (US Board on Toxicology and Environmental Health Hazards 1980, Shusterman 1992).

Olfaction begins when odour-causing molecules are trapped in moist nasal mucus covering the olfactory epithelium. The olfactory epithelium is 75μm thick and consists of three different types of cell. These are odour receptor cells (of which humans have around 10 million), supporting cells and basal cells (Engen 1982). The molecules undergo diffusion to the cilia of the olfactory receptor cells on the first cranial (olfactory) nerve, triggering the generation of nerve impulses to the brain. Each receptor cell acts independently of its neighbours, possibly to maintain a continued response to the presence of an odour (Engen 1982). There are two schools of thought on olfaction. It is thought, on the one hand, that receptor cells will 'recognise' specific odour-causing chemicals (Shusterman 1992). Alternatively, other researchers argue that receptors will be involved in detecting different odours (Engen 1982). Results from experiments in this area are notoriously difficult to interpret. During 'quiet breathing' (US Board on Toxicology and Health Hazards 1980), only 3% of odiferous material will reach and make contact with the olfactory area, set high in the nasal cavity away from the main respiratory tract. In order to increase the quantity of odiferous material reaching this area, sniffing, a conscious drawing of air into the nose, is required. Olfaction has many dimensions including intensity, qualitative odour identification and aesthetic (hedonic) classification (Shusterman 1992). These properties are discussed in greater detail in Section 3.2.

Factor affecting odour perception	Individuals affected by factors	Effects of these factors
Age	**Children**	**Children under 2 years show no hedonic preferences Children 3 years and over start to state preferences similar to adults.**
	Elderly	**Elevated odour detection thresholds Rapid adaption Failure to discriminate**
Health	**Individuals with various health problems**	**Various effects, e.g. asthmatics have elevated odour sensitivity head injury can cause anosmia**
Gender	**Females**	**Reports of females having higher sensitivity, e.g. lower detection thresholds**
Environment	**Employment**	**Occupational exposure to materials can affect olfactory ability**
	Smoking	**May be less sensitive to some or most odours, e.g. higher detection thresholds, or complete loss of ability to smell odours**
Adaption	**Individuals exposed to odour**	**May cause failure to perceive odour**

Table 2.1: Summary of factors affecting the ability to detect odour

Sensory irritation is detected by the trigeminal system, located in the nasal cavity on the fifth cranial nerve (it has a counterpart in the lower respiratory system on the vagus nerve). This system is responsible for the perception of irritancy and pungency in the sense of smell and taste (Shusterman 1992). Odiferous materials that cause irritation, tickling or burning sensations stimulate the trigeminal receptors. The system facilitates protective reflexes when the individual is exposed to irritants that could be injurious to health. These reflexes include rhinitis, lacrymation, reduction of breathing rate and breath holding.

The ability to sense odours and the responses they elicit can vary markedly between individuals. This variability of response arises due to both physiological factors and attitude. Both of these groups of factors affecting the sense of smell will be discussed below. It should also be remembered that the sense of smell of an individual may vary on a daily basis. This has been suggested as a cause of variable results in odour perception trials undertaken by Stevens, Cain and Burke (1988). They argued that apart from aging and health effects, the variable results seen in odour trials may be the product of intra-individual variability of response with time. This generates serious implications for those interested in controlling odour emissions or effects, or those trying to assess the impact of odour pollution if the response of an individual can vary on a short-term basis. There is, however, a great deal of information suggesting that this may not be the only reason for variation of response in odour trials.

2.2.2 Age and the sense of smell

Unlike other factors discussed in this section, it is widely agreed that the sense of smell in an individual will vary during their lifetime. Olfactory perception declines with aging, usually from around the age of 60 (Schiffman 1992, Shusterman 1992). Loss will become more marked at around 70 years. There are three major classes of olfactory loss: anosmia (no sense of smell, see Section 2.2.3), hyposmia (reduced sensitivity to smell) and dysosmia (distortion of normal smell) (Schiffman 1992). Hyposmia is rare, for example it affects around 2% of the general population of the United States; complete anosmia is rarer still, affecting 0.2% (Amoore 1986). Dysosmia, distorted olfactory perception, can take a distinct form referred to as cacosmia, where the distortion is unpleasant in nature (Morresi et al. 1975).

The elderly display the following problems with smell.

- Firstly, they will perceive odours at higher detection thresholds than younger individuals. Experiments carried out by Schiffman (1992) showed that thresholds were 7 to 8 times higher for mineral oil in seventy-year-olds than twenty-year-olds. Elevated thresholds have been recorded for a variety of odours including *n*-butanol, menthol and food odours (Schiffman 1992). Thresholds have varied between 2 to 10 times higher for the elderly than younger people.

- Secondly, the elderly have a reduced ability to estimate the magnitude of the concentration for a variety of odours, pleasant, neutral and foul in nature (Schiffman 1992).

- Thirdly, they have a reduced ability to identify odours (Schiffman 1992).

- Fourthly, they have a reduced ability to discriminate between odours and finally, will adapt, or 'become used to' an odour more quickly than younger subjects. In an experiment conducted by Schiffman, adaption was shown to be complete after four sniffs in older subjects as opposed to 8 to 16 sniffs in the young. These factors have been demonstrated experimentally, using a variety of odiferous materials (Schiffman 1992).

The causes of this olfactory loss are linked to changes in the anatomy and physiology of the olfactory system. They include structural alterations in the olfactory epithelium and atrophy in the olfactory bulb and nerve.

There has been comparatively little research carried out into the sense of smell in children (Wysocki et al. 1992). What has been reported suggests that children are as sensitive to odours as adults, but researchers have concluded that children do not have aversions to odours found offensive to adults. This may be the result of children being more tolerant of odours than adults or their range of hedonic experience being less than adults (Wysocki et al. ibid). It is believed that children begin to acquire odour preferences from late infancy onwards (Wysocki et al ibid.).

2.2.3 Health and the sense of smell

The physiology and health of an individual may affect their sense of smell. As with qualities such as eye colour, our sense of smell is inherited. This may result in specific anosmia, what Dodd (1980) has described as 'an olfactory analogue of colour blindness'. Simply, this describes the inability of an individual to detect certain types of smell. This arises from their not having particular types of odour receptors or having altered receptors present in the nasal cavity (Wysocki et al. ibid.). It is thought that some individuals however may experience anosmia at lower odour concentrations only. They may be able to detect an odour, but at markedly higher concentrations than most (Wysocki et al. ibid.). This phenomenon is termed hyposmia.

The health of the individual is known to affect odour perception. Diverse medical conditions such as head trauma, Migraine, Multiple Sclerosis, cirrhosis of the liver, Diabetes mellitus, Sinusitis and polyposis, viral infections and psychiatric disorders are known to affect the sense of smell (Schiffman 1992). For example, head injuries are known to trigger anosmia and viral infections, such as colds and influenza can cause parosmia. Cacosmia can arise from decomposing tissue associated with oral or sinus infections. Increased sensitivity to odour can result from bronchial asthma or from pregnancy (Shusterman 1992).

Drugs will also affect the sense of smell. There is a wide range of medication involved in such effects. They include anesthetics, such as cocaine hydrochloride, antianginal drugs and vasodilators such as dilitiazem, antimicrobial drugs such as streptomycin, opiates and sympathomimetic drugs such as amphetamines. For example, cocaine is believed to affect the olfactory epithelium and cause anosmia. Radiation therapy to the head can also affect the sense of smell (Schiffman 1992).

2.2.4 Gender and the sense of smell

Reports have differed on whether the sense of smell between men and women varies. Shusterman (1992) reports in his review that females are found in most studies to be more sensitive to odours than males. This is confirmed by Cheremisinoff (1992).

Koelega and Köster (1974) investigated differences in olfactory ability between men and women. They found that women were more sensitive to a wide range of odours than men. They found larger differences in perception occurred in what they termed 'biologically meaningful' materials than with 'neutral' ones. Interestingly, differences in perception between the sexes did not occur in children or adolescents.

2.2.5 Degradation of the sense of smell

There are a number of factors that are under the control of the individual to varying extents that may affect his or her sense of smell. The first factor is occupational exposure to materials such as various organic and inorganic chemicals, metals and dusts known to affect olfactory ability.

Exposure to materials affecting olfactory ability can be acute, lasting seconds, minutes or hours, or chronic, lasting months or years, in nature (Amoore 1986). Acute exposure can cause temporary hyposmia (lasting minutes), recuperable hyposmia (lasting weeks) or permanent hyposmia (lasting years). Chronic exposure can cause recuperable or permanent hyposmia (Amoore 1986). There are many materials and processes responsible for olfactory damage. Metallic processes causing permanent hyposmia after chronic exposure include zinc and steel production and nickel and silver plating. Dusts that can cause permanent hyposmia include cement, printing, hardwoods, chalk and potash. Non-metallic inorganic compounds that can affect the sense of smell include carbon monoxide, sulphur dioxide and oxides of nitrogen; and organic compounds include benzene, menthol, chloromethanes and trichloroethylene (Emmett 1976, Amoore 1986). Emmett (1976) related the case history of an otherwise healthy pipeworker who experienced olfactory problems after exposure to a variety of solvents, such as acetone. Not only did this individual experience elevated detection thresholds for certain types of odour, by also problems with taste and cacosmia, unpleasant sensations when exposed to perfumes and certain fumes. This was, as explained by Emmett, a typical case of olfactory damage resulting from exposure to industrial chemicals.

The pathological basis for hyposmia after occupational exposure to such materials can take three forms (Amoore 1986). Respiratory or mechanical hyposmia can result from blockage of the upper airways by, for example tumours, polyps or oedema. Secondly, there is essential hyposmia, resulting from damage to the olfactory mucosa and nervous receptors and thirdly, central or intercranial hyposmia where the olfactory bulbs or brain are damaged..

The second behavioural factor believed to affect the sense of smell is smoking. There is some conflicting evidence as to how important this factor is. Venstrom and Amoore (1968) carried out experiments to ascertain if age, gender or smoking affected olfactory ability. They reported that smokers had marginally reduced detection thresholds for two odour-causing compounds out of a range of ten selected for the experiment. The authors did not state what these odour-causing compounds were. Amoore (1986) wrote that smoking will not affect sensitivity to odour, but went on to say that extreme use of nicotine will cause chronic hyposmia. Ahlström et al. (1987) examined olfactory perception in groups of smokers, passive smokers and non-smokers using two test substances, *n*-butane and pyridine. Their results showed that smokers had reduced sensitivity to both odours. They suggested two alternatives for these results. Firstly, that smokers were used or habituated to odour. They defined habituation as 'the cessation of a response because of a learned adjustment to a stimulus situation as distinguished from a decrement in sensitivity to it'. The results obtained from smokers were similar to those obtained from individuals overexposed to motor oil odour. Alternatively, and the authors suggested that many would prefer this interpretation, smokers have a reduced ability to detect odour, that is hyposmia. Ahlström et al. went on to discuss experiments showing that smoking has no effect on smokers' sensitivity to 3 odour-causing compounds, butyric acid, triethylamine and ethyl mercaptan, both components of landfill odour. Passive smokers reported odours as being weaker than the nonsmokers. Shusterman (1992) in his review reported that the current feeling of researchers is that smokers will experience reduced sensitivity to odours. Cheremisinoff (1992) also reported that non-smokers have greater sensitivity to odour. Koelega and Köster (1974) found in their experiments in examining differences into olfactory ability between men and women that their results were affected slightly by smoking, smokers having reduced sensitivity to odour-causing compounds.

2.2.6 Exposure to Odiferous Sources

The next factor to be considered does not directly relate to the individual's ability to detect odour but may influence the level of their exposure to it, and that is their lifestyle. In order explain this, it is necessary to examine the impact of another atmospheric pollutant, namely ozone (O_3). It is believed that levels of ozone are lower indoors than outdoors due to scavenging of ozone by indoor surfaces and lack of internal sources (Lippmann 1989). Individuals who are frequently out of doors experience greater levels of exposure than those who are not. Similarly, in the case of odour, a similar picture may arise. Individuals may be more likely to experience odours out of doors than indoors, due to deposition or reaction of odour causing compounds with surfaces of buildings and other materials (Summer 1971). This may mean that an individual who, for example, is outside gardening may experience odour more frequently than a neighbour who does not go outside as frequently or for as long a time. Although the potential for odour nuisance may be the same for both individuals, their lifestyle may explain why one person may experience nuisance and the other not. The same could be said for individuals who are frequently away from home and therefore away from an odour source. They may experience less odour nuisance than someone who is at home more frequently. Alternatively, they may perceive odour more frequently as they are not habituated or 'used to' an odour. This is discussed further in the next section (Section 2.3). Interestingly, ozone can be used as an odour-masking agent. It acts, as Cain (1980) states, either as an 'olfactory anaesthetic' or is able to react with odiferous compounds (ozone is extremely reactive), altering their odour qualities. It is possible, therefore, that the presence of other atmospheric compounds may affect odour perception, either by affecting the individual's ability to perceive odour or by interfering with the odiferous compound itself.

Apart from levels of exposure to odour, there are two other factors to consider when considering the impact of odour pollution. These are adaption to odour and how the judgment of an individual may influence their assessment of how badly they are affected by an odour. Adaption is discussed below and in Section 2.3. Individual judgment is discussed in Section 2.3.

2.2.7 Adaption

Cheremisinoff (1992) explains that there are small variations frequently taking place in the environment. In order to accommodate these changes, an individual will unconsciously alter their response. If an odour produces a certain stimulus in the nose, with continued exposure sensitivity to this particular stimulus will decline. This is termed adaption. With high odour concentrations this decline occurs quickly (Cheremisinoff 1992). At extremely high levels, certain odiferous compounds, such as hydrogen sulphide (H_2S), can induce the phenomenon of olfactory fatigue or paralysis. This means that an individual is unable to detect the odour at all (Cheremisinoff 1992, Shusterman 1992).

However, as Cain (1980) observes the usual experience of odour is one where although adaption takes place, an odour may still be perceived for as long as it is present. That, as Cain stated '...perceived magnitude showed no inclination to decline to zero sensation level'. Engen (1982) also reported that adaption can occur rapidly, but the odour may still be smelt. Typical adaption times result in a reduction of sensitivity to an odour of approximately 60% over the space of several minutes (Shusterman 1992). Engen (1982) states that adaption is 'overemphasised'. He states that habituation is more likely, where an individual experiences a progressive reduction in response to an odour over time. That is, the individual simply 'becomes used to' an odour. The means of application of an odour can affect adaption rates (Cheremisinoff 1992). For example, the reduction in sensitivity is less if an individual smells two odours instead of a single one. Although adaption can take place rapidly, it is reversible, recovery taking place over the space of a few minutes (US Board on Toxicology and Environmental Health Hazards (1980).

2.3 External influences, judgment and response to odour

Assessment of odour impact involves not only the ability of the individual to perceive the odour, but also their personal assessment of the odour and on a larger scale, the interactions of the perception and attitude of the community.

When an individual perceives an odour, they will also be affected by what could be considered external factors. They will make an assessment of an odour based on its properties, such as its pleasantness and intensity, as well as its duration and how frequently it is detected. Repeated exposure will lead to a form of self-education (2.3.1). Together with personal attributes such as those discussed in Section 2.2, this leads to experience of the odour in the context of the individual and their environment. Experience and personal factors, together with social factors (2.3.3), for example adverse publicity relating to an odour source, will lead to the individual's judgement of the odour. This section examines these factors in some detail. An overall

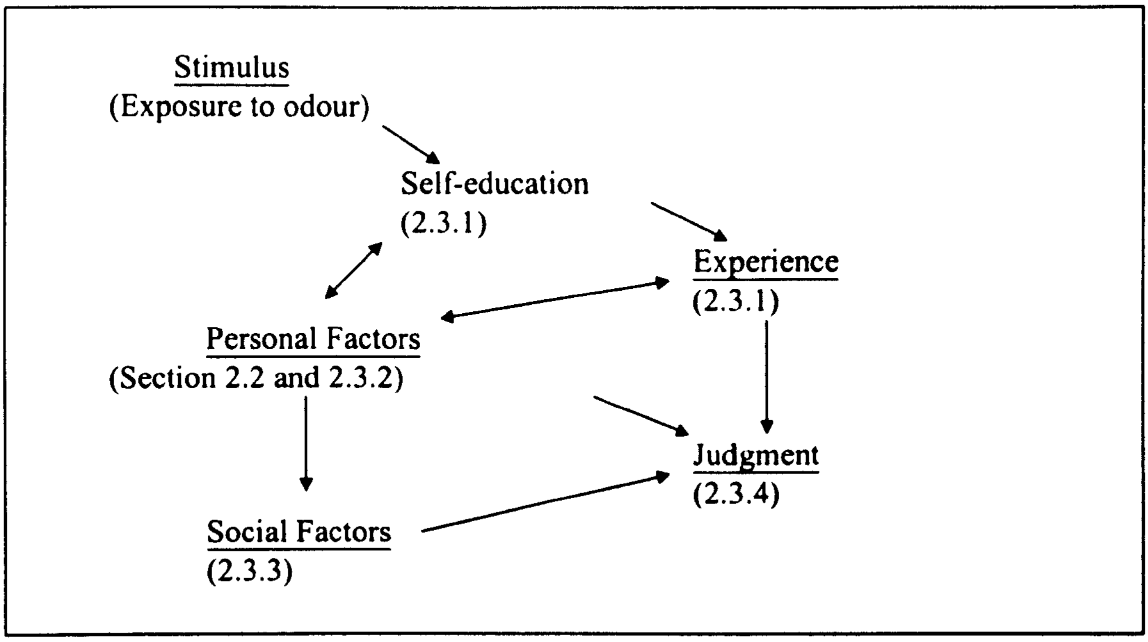


Figure 2.1: Factors affecting perception of the individual and their interrelationship

summary of the components of this section and their relationships are summarised in Figure 2.1.

2.3.1 Learning, experience and perception

The exposure to odour acts as a stimulus for the factors and processes above to occur. The first of these is what Vickers (1983) terms self-education, where exposure to a situation leads to learning or experience of a particular phenomenon. This experience or learning leads to what Vickers refers to as 'readinesses', resulting in the inclusion of certain facets of a problem or situation in a judgment or decision and others being excluded. Vickers refers to this as classifying and valuing certain aspects of a situation "in this way rather than in that". When examining odour impact, learning experience is important in how the odour would be perceived. For example, Cain (1980) wrote that questions should be asked about how representative data collected by odour panelists is of impact on the general population near an odour source. He reported that the panelists may have years of 'practice' at detecting odour and this 'practice effect' may lead to bias in reporting rates. Engen (1982) wrote that false alarms in olfactometry trials tend to decrease with increased experience. Shusterman (1992) reported in his review that "subtle types of associated learning may influence individuals' responses to environmental odours".

2.3.2 Personal factors affecting perception in the individual

Another component of the judgment and decision process is the individual's personal factors. The physical factors associated with health or factors affecting health such as smoking, which influence odour perception have been noted above. There are others, possibly more subtle, that also affect perception. These include several factors identified by Cederlöf et al. (1964). They are the individual's satisfaction with the surrounding area, their propensity to complain, their tendency to anxiety and if they have a personal connection to the odour causing process. Cederlöf reported that the first three factors will increase the frequency of complaints about odour. However if the individual is, for example, employed by an operator of an odour causing process, they are less likely to report being affected by odours. What has been termed 'environmental worry' may influence perception of odours (Shusterman 1992). Ordinarily, environmental worry has been associated with sites of environmental concern such as toxic waste sites or situations such as the disabled Three Mile Island nuclear power station. However, concern about a less threatening odour causing process may also cause an increase in sensitivity to odour. Cederlöf et al. wrote that reports of odour pollution from pulp mills have been made when odour-causing compounds have been absent from the environment.

As Craik (1987) explains, when attempts are made to quantify the impact of any kind of environmental annoyance, account must be taken of "non-environmental irritants and hassles of everyday life". He goes on to state that "environmental annoyances join in with these other hassles in an aggregated impact upon individuals' well-being and quality of life". Thus whenever an assessment of environmental impact on people is undertaken, it must be remembered that their decisions are not always as objective as would be liked. The difference between what happens at an odour source and what is perceived in the population is a critical factor to be considered when environmental impact is assessed.

2.3.3 Community factors affecting perception

There are social factors that may influence response to odour. For example, landfills are frequently cited as the cause of different types of nuisance, for example odour, and this may affect a community's perception of them. Furuseth (1990) conducted research into the impact of landfill on affected communities. The landfill, although well designed and well managed, was perceived by the local community as having serious economic and environmental effects. This included odour pollution. There was opposition to establishment of the site from the outset and periodically, there are still complaints about operating standards. Schiffman et al. (1995) and Sweeten and Miner (1993) reported similar problems associated with odours from commercial pig and cattle operations respectively. Communities are found to be likely to experience dissatisfaction and complain when they feel the quality of their overall environment is affected (Shusterman 1992). When there is general dissatisfaction with their environment and an odour causing process is uppermost in the minds of the individuals making up the community, it is not surprising that an individual's response to odour may be influenced. Complaints may relate to the number of times odours are reported, the hedonic properties of the odour and any effects odours may have either on the individual or the general environment.

2.3.4 Judgment and odour events

All the above factors, operating on both on the personal and community level, form the input to the action of the individual when they perceive an odour event. They will base their identification of the odour, its intensity and hedonic properties and how serious a nuisance they believe it to be using the physiological 'equipment' they have and the experience they have gained from previous exposure. Additionally they may be influenced by their own and the community opinion of the odour source. As

Cederlöf et al. (1964) mentioned some individuals are more likely to complain, they have a propensity to complain, and this may affect who complains most frequently. If a nuisance causing process is generally unpopular with a community, it may generate complaints no matter how professionally undertaken it is. Conversely, Cederlöf et al also described how people associated with the source of a nuisance, for example if they are employed by the operator, may be less likely to report nuisance.

This situation was designated the "appreciative system" by Vickers (1983). He described how when an individual makes a decision or undertakes an action, they take into account some factors but not others. These he referred to as learned interrelated readinesses, where an individual gives various weightings to aspects of a situation, deciding that certain features are more or less important. The benefits of this are that experience and decisions facilitate further learning, enabling the individual to recognise and respond to a stimulus. For example, an individual may experience odour nuisance from a source with certain weather conditions, for example when the wind is blowing in a particular direction. They will learn that odour nuisance is associated with wind direction and will anticipate nuisance under certain conditions. However, as Vickers goes on to explain, readinesses can have negative effects. They may for example limit an individual's thinking and lead to an incorrect judgment or decision being made. Vickers goes on to say that "...physical perception [is] dependent on learning perceptual categories" and these categories are used to classify experience. For instance an odour from a second source, but in the same direction as the original odour source, may be perceived by the individual. As the wind direction is in the usual direction for nuisance from the original source, the individual may decide the nuisance has been released from the original source, even if the odour has different properties. The individual has based their judgment on selective aspects of the situation.

2.4 Conclusion: The need for a population response model

The existing approach to odour assessment consists largely of measurement and analysis of odiferous compounds emitted and dispersion modeling. The results will indicate concentrations of odour-causing compounds at a particular location. However, this cannot indicate the extent of odour impact on individuals at the same place.

What is perceived by the individual may not reflect the concentration of the odour-causing compound. What they perceive is a result of the interplay of the state of their sense of smell as well as external factors such as their experience, attitude and judgment. Namely, the physiological, perceptual and behavioural components discussed in this chapter. Additionally it should be remembered that the affected individual does not live and perceive odours in isolation, but will be influenced by information and the attitudes and perceptions of others. All these factors form the appreciative system of the individual. This is illustrated in Figure 2.2.

An individual may detect an odour depending on their olfactory ability. They will use their judgment about its properties, such as its source and its pleasantness. Then they will make their response. Their behaviour may influence the individual's exposure levels and their experience of the odour. These attributes will operate whenever odour is present. They will vary between the individuals in the community, and as a result, the response and annoyance produced will vary also. Attempts to assess the impact of odour must take this variability into account. Currently, it is ignored or assumed to be unimportant. Ignoring it may lead to inaccuracies in impact assessment.

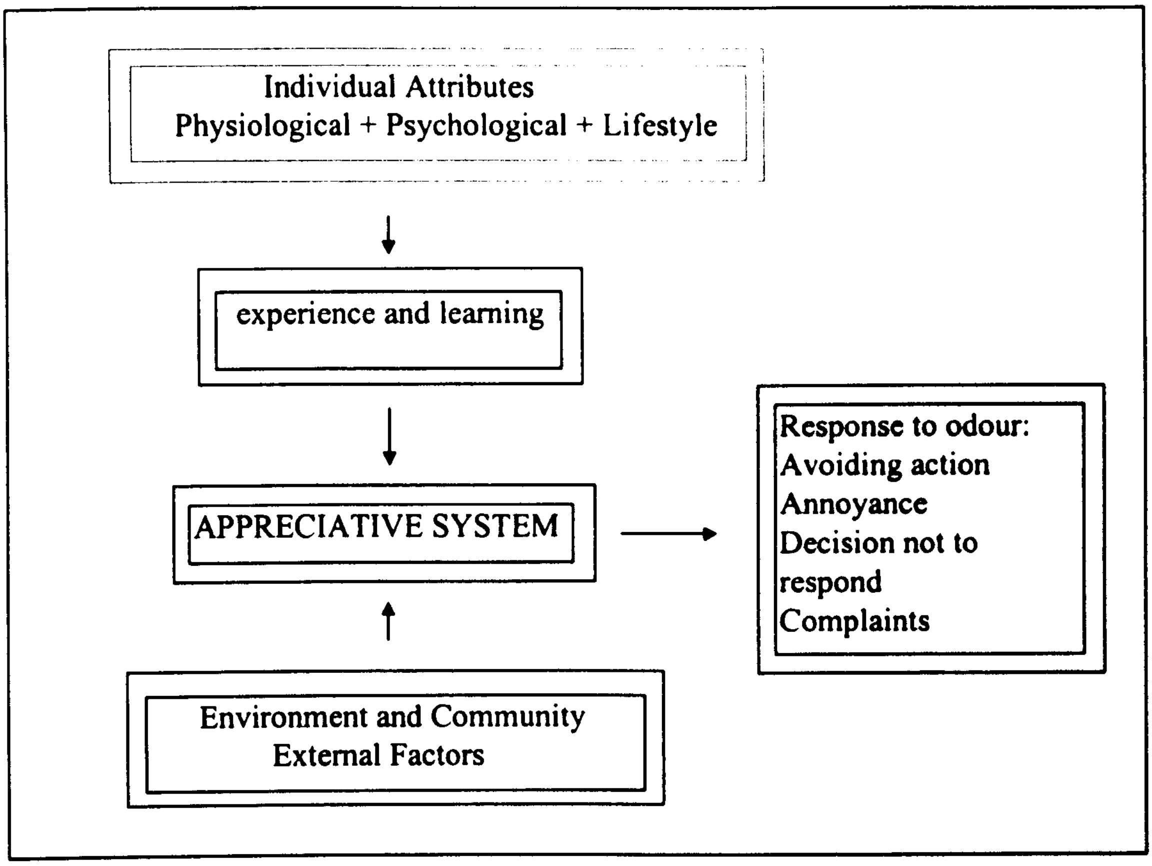


Figure 2.2: Factors operating on an individual leading to response to odour

A method of assessing odour impact that includes the perspective of the affected individual and community is required. A means should be available of taking into account at least some of the factors above and how they will affect the impact of odour on an individual. These would include the age, behaviour and attitudes to odour sources of an individual. In the following chapters, a method incorporating the factors discussed above when assessing the impact of odour on a community will be developed. In Chapter 3, a discussion of the techniques available to researchers in odour impact studies is given.

Chapter 3

Odour monitoring methods and techniques

3.1 Introduction

The study of odour consists of two forms of approach. These are firstly, instrument-based approaches and secondly, approaches that involve using the perceptions and responses of people. The second approach consists of using questionnaires of some form, analyses based on reports or complaints concerning odour and finally the use of panels of individuals. This type of approach is undertaken to establish the impact or extent of environmental odour of communities or individuals in those communities. The two forms of approach are not strictly separated and can be used together, although many studies do not seem to use more than one technique. Clarenburg (1987) and Zeiss and Atwater (1993) used mathematical models to estimate odour impact. Goldsmith (1973), Hellman (1975) and Sweeten and Miner (1994) used different types of odour panel for their research. None of these researchers used any other type of technique in an integrated fashion. One study by Bruvold and others (1983) used instrument and sensory techniques together (see Section 3.4). Their work involved measurement of odorous gases at selected locations and social surveys in the affected populations. Such surveys are, however, the exception not the rule.

A premise of this thesis is the use of monitor panels (a sensory technique) can be used to generate a population response model to gain greater insight into odour impact. This would provide an improved understanding of affected locations and odour the effects of odour on the community.

In Section 3.2, different terms associated with odour research are reviewed. In the subsequent sections, Sections 3.3 and 3.4, methods of odour assessment are discussed together with their positive and negative aspects. Odour monitoring panels are discussed in detail as this the method of community impact assessment used in this research.

3.2 Key concepts in odour studies

There are key terms that are used in the field of odour research and which are used in this thesis. They form part of a branch of science termed Psychophysics. This involves measurement of sensory stimuli, either perceived intensity as a function of exposure or the minimum level of exposure needed to generate a response. The relevant terms for odour research are odour threshold, quality, character, hedonics, odour intensity and frequency. Each term will be discussed in turn. Firstly, however, the units of odour measurement will be discussed.

3.2.1 Units of odour

Odour measurements can involve the use of different types of unit, which are outlined below. Firstly, as with other atmospheric compounds, the concentrations of odour causing chemicals can be measured in ppm or ppb (parts per million or parts per billion by volume respectively). Alternatively, they may use, in certain cases, such as in measurement of particulate matter, $\mu m/m^2$ (micrograms per metre^2). Two other units of measurement specific to odour may be used. These are firstly, odour units, "ou", and secondly, odour units per cubic metre. "ou/m^3" (Harssema 1987). An odour unit is difficult to define as it relates to physiological effects (Timbrell 1989, Van Harreveld 1997). It is compared to the ED_{50} tests used in toxicology trials where a response is detected in 50% of a test population. In the case of an odour unit, 50% of the population studied will detect a sensory stimulus, in this case an odour when exposed to an odour-causing chemical. Odour units per cubic metre represents the quantity of odour units dispersed in a cubic metre of air which is detectable by 50% of a human odour panel (Van Harreveld 1997).

3.2.2 Odour thresholds

There are two different types of threshold that frequently appear in the literature. The first of these is referred to as the stimulus or detection threshold (Engen 1982). This refers to a concentration of odour where an individual can just detect the odour. This point is usually defined where an individual can successfully identify the odour concentration 50% of the time in trials. The 50% response level in odour trials is standard practice in olfactometry and again is equated to the ED_{50} dose in toxicology trials (Flesh and Turk 1975). As Engen states, this is the most frequently used threshold as it is the simplest one to obtain. The other threshold referred to frequently is the odour recognition threshold. This is the point at which an individual can not only detect the presence of an odour, but can also identify what the odour is or could, if they had no experience of the odour, describe it.

Odour thresholds are obtained by laboratory experiments using panels of volunteers. The means of presenting an odiferous compound will vary, but the objective, that of obtaining odour thresholds, is the same. The simplest method is that of using sniff bottles, flasks containing a known concentration of the odorous compound. The bottles are given to volunteers, who sniff (see 2.2.1) from them and give their response. When a threshold is sought, a series of bottles with differing concentrations of the odorous compound will be used. The compound will be diluted with a suitable diluent, for example water, mineral oil or benzyl benzoate. The concentrations will usually be successively halved until the volunteer states that they can no longer detect the odour (Engen 1982). This method is noted for its flexibility and ease of use. There are some limitations with this method. Volunteers may vary in their strength of sniffing. This has been overcome by researchers adapting the stoppers used in the flasks so when an individual inhales too strongly, the stopper closes (Engen 1982). A more sophisticated method is that of using olfactometers (Engen 1982). An olfactometer is a device designed to control and manipulate the concentration of odorous compounds (Engen 1982). A measured sample of the odorous compound, whose purity has been tested by gas chromatography, is placed in an olfactometer. It is delivered to a volunteer via a sniffing port, which takes the form of a nosepiece or funnel. Olfactometers usually deliver the sample material to the volunteer at body temperature in a gentle flow whose rate is close to normal breathing (Engen 1982). Nitrogen or odourless air is usually used for diluting the sample. The gas is saturated with the compound by passing through a bottle containing the liquid odour-causing compound. Further dilution then can take place by mixing with purified air using a sparger. Olfactometers can vary from simple types, with one channel for testing one odour-causing compound at a time, to elaborate ones that can be used to test different concentrations of odour-causing compound or different types of compound at the same time (Engen 1982). Not only pure compounds can be tested in this way. Samples of air contaminated by odour may be taken from the environment and be taken to the laboratory for testing (Jones et al 1992).

There are, as Shusterman (1992) points out, difficulties with the identification of odour thresholds as they are extremely dependent on the conditions under which they are obtained. Single-sample methods involve the presentation to subjects of a series of different concentrations of an odour. This has two sources of error. Firstly, anticipation of concentration can occur if concentrations are presented in ascending order or fatigue (see Chapter 2) occurs if odours are presented in descending order. Secondly, differences can occur in different subjects' judgement of an odour (Shusterman 1992). The multiple-sample methods involve the presentation of several dilution ports to the subject and asking them which one contains the odour. This usually reduces variability in results than the single-sample method. The final method is referred to by Shusterman (1992) as the method of extrapolation of intensity response. This involves generation of intensity scaling data above an odour threshold and then the extrapolation of the data to produce an odour threshold.

3.2.3 Odour hedonics, and quality and character

The pleasantness or unpleasantness of an odour is described as its hedonic property. Researchers have an interest in these properties of odours, which is how they smell to someone exposed to them. Odour hedonics is less precise than threshold measurements (Engen 1982). It is recognised that odour preference is unique to the individual. This is illustrated by an experiment discussed by Cheremisinoff (1992). Sixteen different odorous compounds were presented to 100 subjects. There was some agreement about certain odours, such as vanillin and menthol, which were recognised by 93 and 62 individuals respectively as being pleasant. However, odour causing compounds that would largely be considered unpleasant, such as n-caproic acid and heptyl aldehyde were considered pleasant by 9 and 7 individuals. The complete results are shown in Table 3.1.

As Cheremisinoff explains, although there is general agreement on most odours as pleasant or unpleasant, there are also idiosyncrasies to be found in the sense of smell. Some people will complain about the smell of manure, others will find it inoffensive (Engen 1982). This variation could affect if and when individuals complain about environmental odours. Judgements about odours will also be influenced by the experience and emotional context of the subject (US Board on Toxicology and Environmental Health Hazards 1980).

Of course, the hedonics of an odour are dependent on factors other than the actual smell. Some odours can smell pleasant when faint, yet may become unpleasant when stronger. Additionally, when an odour is present continuously in the environment it may cause annoyance even if it is a pleasant one. As Cheremisinoff puts it, "If an odour 'does not belong' it is objected to". This may explain why, when operators of an odour causing process use masking odours to disguise an unpleasant odour, they may continue to receive complaints. Summer (1971) succinctly sums it as "using a stink to disguise a stink".

Odorous compound	Pleasantness (group of 100 subjects)
Vanillin	93
Methyl salicylate	90
p-dichlorobenzene	83
Geraniol	81
Camphor	70
Menthol	62
Empty bottle*	61*
Acetophenone	56
Diphenyl ether	44
Phenol	31
Ethyl cinnamate	31
o-bromtotoluene	20
Nitrobenzene	15
Quinoline	15
n-caproic acid	9
Heptyl aldehyde	7

* Control

Table 3.1: Results of trials rating various odours to pleasantness
(From Cheremisinoff 1992)

Odour "quality" or "character" are technical terms referring to the properties of an odour that enables an individual to distinguish it from another (US Board on Toxicology and Environmental Health Hazards 1980). Attempts have been made to identify primary odours to classify these properties, such as floral, fishy, minty, garlic and so on. Research into odour character usually involves the provision of lists of types of odour for trained subjects to use when sniffing odours. With some practice, subjects usually become quite adept at describing odours presented to them (Cheremisinoff 1992). Together with odour hedonics, odour quality can trigger strong reactions in an individual as odour has been associated with arousing emotions and memories (Engen 1982).

3.2.4 Odour intensity

The term odour intensity refers to the intensity of the odour perceived without knowledge of the concentration or dilution. The intensity is related to concentration thus,

$$\text{Intensity of odour} = K\,C^n$$

Where C is the ambient concentration of the odour, K is a coefficient and n an exponent (Cheremisinoff 1992). For most odours, the value of n varies between 0.2 and 0.8. In order to reduce the intensity of an odour with a value of n = 0.25 by a half, it would have to undergo dilution by a factor of 16 (Cheremisinoff 1992). This illustrates the difficulties of operators of odour causing processes if they rely on dilution as a means of odour control. The quantity of clean air to be used must be substantially greater than the odoiferous air to be diluted.

The perception of odour intensity follows a logarithmic function of the odorous gas concentration (Diaper 1987, Pagé, Guy and Vigneron 1997). Perception of the intensity of an odour decreases over time due to adaption (see 2.2.7).

3.2.5 Odour frequency

An odour is present when the threshold concentration is exceeded (Harssema 1987). The length of time an odour is present will be affected by its dispersion in the atmosphere, that is which direction air movement carries it, and by physical and chemical processes operating on its components (see Section 4.4). Odour frequency refers to the periodicity of odours, the occurrence of an event per unit time. For example, are odours perceptible on an hourly, daily or weekly basis? Or are they infrequent, being present only once a monthly or over a longer period. The frequency of an odour in the environment may contribute to the level of nuisance it may cause, particularly in association with other factors such as odour intensity and hedonics. Diaper (1987) describes how the number of complaints varies with wind speed and direction. Complaints were, he noted, more likely under conditions of a high speed veering wind, rather than a low speed non-veering wind. Perceived nuisance can be caused by brief exposure, lasting only seconds, especially if frequently repeated (Diaper 1987). The length of time an odour is present in the environment is an important factor in influencing adaption and habituation (see 2.2.7 and 2.3.1) (Harssema 1987).

3.3 Instrument based odour assessment

This section briefly summarises the most widely used technologies for quantifying environmental odour pollution. It includes techniques used in the laboratory and those used in the field. It also briefly covers dispersion models used to estimate odour released into the environment. These techniques are summarised in Table 3.2.

3.3.1 Instrument based techniques

Instrument-based techniques for measuring ambient odour pollution can be divided into two groups. These are sampling of air and use of real-time instruments (Shusterman 1992). Such sampling and analysis usually involves collection of an air sample containing odiferous gases and use of gas chromatography and mass spectroscopy to analyse the odour-causing compounds present in the sample. Odour collection involves taking air samples using adsorbent resins, stainless steel canisters or Tedlar bags (bags with non-absorbent surfaces used for odour sampling). The major consideration is that the equipment used does not have surfaces that react with odour causing compounds , as such chemicals can be highly reactive, which may affect the analysis. The atmosphere to be sampled is collected over a set period of time. The sample is then analysed using gas chromatography and mass spectroscopy is to identify what odour causing compounds are present and in what quantity. Calibration can be undertaken using permeation tubes that release vapour at a defined rate. Slater and Harling-Bowen (1986) used this technique to sample and analyse sulphur gases (hydrogen sulphide and methanethiol) as well as volatile sulphur compounds (higher thiols and organic sulphides) present in ambient air and air containing ozone. The results obtained are usually more sensitive than those from real time instruments and a large number of chemical species can be analysed (Shusterman 1992). Care must be taken to ensure that sampling takes place at a time when odour is at its peak and that contamination by other materials is avoided (Shusterman 1992). Such techniques are quantitative in nature, not necessarily qualitative. The results do not reflect the impact of the odour on individuals and communities.

Technique	Example	Advantages	Disadvantages
Instrument based methods	**Sampling + GC-MS**	**Can identify and quantify odorous compounds in air samples**	**No qualitative data - will not reflect community impact**
	Real-time device e.g. electronic nose	**Useful for identifying concentrations over short-term**	**May be less accurate than GC-MS** **No qualitative data**
Dispersion models		**Can be cheap to use** **Ease of use** **Can be used to estimate concentration at distance from source**	**Need detailed data e.g. emissions** **Assumptions of dispersion and topography** **Limitations of meteorological data** **No qualitative data**

Table 3.2: Odour assessment techniques reviewed in Section 3.3

Real time instruments, such as the multi-gas sensor system or 'electronic nose' are useful for analysing variations in odiferous chemical concentration, particularly over the short term (Shusterman 1992, Ramalho, Regui and Kirchner 1997). The results may be less accurate than those obtained using sampling and laboratory analysis and there may be problems with selectivity or recognition of specific odour-causing compounds. Unlike the human nose, an electronic nose has to contain sensors designed to identify a specific odiferous compound, otherwise it will not be recognised. Odour-causing gases produced by a particular source may consist of more than one chemical and it may not be possible to identify fluctuations in the different components of the odour. Fluctuations of an odour plume concentration may occur due to eddying and dilution by the wind (see 4.4.3 for a more detailed description of an odour plume and its behaviour). Also, sources such as landfills that can release many odiferous gases, may not release an odour plume with the same constituents or the same constituents in the same quantities continuously (see Section 4.4 for a more detailed description of a landfill as an odour source). Such fluctuations may affect the qualities of the plume and hence the nature of the exposure of the community (Shusterman 1992).

The most sensitive equipment available to assess odour properties on people is the human nose. Human beings can detect odours at concentrations as low as 10^{-9}ppb (vol.) (Cheremisinoff 1992). It can be difficult to measure odour-causing chemicals at such low concentrations using chemical techniques. Use of laboratory techniques to measure odours at such low concentrations requires a pre-concentration phase before analysis.

3.3.2 Dispersion models

In air pollution modelling, Guassian models are the most frequently used. Gaussian models are based on the Gaussian distribution (bell-shaped curve) and assume that almost random atmospheric turbulence will mix pollutants so that their concentration is distributed bi-nomially around a plume's central axis. That is, plume concentration forms a normal distribution in both the vertical and horizontal axes (Oke 1992). They are used to make estimates of concentrations at distance from the source and exposure levels predicted (Punter 1987). Models can be convenient to use and cheaper than analysis of ambient air (Harssema 1987).

There are a number of limitations associated with such models, including uncertainty in input data, the approximations inherent in models, fluctuations in concentration and the intrinsic variability of dispersion (Thomson 1994). Firstly, data is needed on emission rates, that is the release rate of pollutants from their source, which may be straightforward to obtain for point sources, but not area sources, such as landfills. It will become apparent from Section 4.4, that there are many possible sources for odour emission, such as raw wastes, decomposing wastes, gas extraction networks and chemical treatment plants. These sources may or may not be releasing unknown cocktails of compounds at unknown emission rates. Such complex source types include not only waste disposal, but sewage treatment plants, and agricultural sources. It may not be obvious which activity or area is leading to the release of odour causing compounds, and as landfills can be large, the assumption that the whole area of a landfill is one point source can lead to an inaccurate prediction of emissions. Use of point source models together with emission rates from area sources can lead to overestimation of concentrations over short distances. This can be overcome by use of area-source models or by dividing the area into a number of small point sources (Harssema 1987). Secondly, disagreements can arise over which units are appropriate to use. Harssema explains that the odour unit per metre cubed is "an 'amount' of odour analogous to mass (μg) of other air pollutants". An odour unit, he suggests is a ratio of concentration to threshold, where the emission rate is proportional to the volume of air needed to dilute the emission to threshold. Alternatively, Mortensen (1995) states that in his opinion use of the odour unit is inappropriate for use in dispersion models as such units are not representative of plume concentration.

Additionally, the meteorological data used with such models may not be collected from the landfill site and therefore cannot take into account localised climatic conditions or effects of local topography. In turn this will influence the predictions of pollutant dispersion. Also, the data are likely to averaged, usually over an hour, and therefore factors such as veering winds and changing wind speeds cannot be taken into account in the model's calculations.

Also, as Punter (1987) explains, while it is acceptable to assume that in the absence of odour there is no effect on the population, it is not reasonable to assume that when an odour is present there is annoyance. Some odour-causing compounds have to be present in the environment in large concentrations before they will have an impact. As Punter suggests, pine forests have odour concentrations of 20 to 40 odour units, a high odour unit value, but the odour is not likely to produce complaints. Conversely, there are compounds, such as ethyl mercaptan (which has an odour threshold value of 0.00019mg/l), which even in small concentrations will smell unpleasant. Reliance on concentration of an odour-causing compound is not necessarily a useful indicator of odour pollution impact.

3.4 Assessment of odour impact using sensory techniques

There are diverse types of odour assessment using sensory techniques, which involve individuals as judges to assess different aspects of odour. Research based on such techniques involves the use of complaints, surveys and questionnaires. Other types of assessment include olfactometry, namely the use of panels of volunteers sniffing odours in laboratories or out in the field (See 3.2.2). This section discusses the different types of approach, but largely concentrates on the use of monitor panels.

3.4.1 Use of complaints, surveys and questionnaires in odour impact assessment

One of the first indications of odour pollution is complaints either to the operator of the odour source or to local authorities. There have been efforts to analyse complaints and use them to quantify the extent of odour problems and to model levels of community response to odour. One such attempt is that of Clarenburg (1987), who examined odour impact in the Rijnmond area of the Netherlands, a major industrial area of the Netherlands. Residents living close to this industrial area began to complain about different problems, including odour pollution. He generated a mathematical model based on odour emission at ground level from industrial sources. He took into account how odour pollution could spatially and temporally vary due to prevailing atmospheric conditions. He also took into account more than one point source operating in the area. Dispersion of the odour-causing pollutants was modelled and the results obtained indicated the impact of odour with distance from the odour sources and the number of complaints produced. Clarenburg compared the predictions of exposure from his model with data from a survey and from complaints recorded by a local authority in six areas. The results from this comparison are shown in Table 3.3.

The survey asked respondents if they were bothered by air pollution. Two answers were acceptable, yes or no. He went on to use this model in the Rijnmond area using

Residential area	"yes" % of population predicted	"yes" % of population polled	± 95% confidence level
3	**80.5**	**83**	**± 11.5**
2	**50.5**	**51**	**± 13**
5	**32**	**35**	**± 10**
4	**41.5**	**34**	**± 9.5**
1	**27**	**26**	**± 5**
Geleen	**47**	**47.5**	**± 4**

Table 3.3: Comparison of predicted and actual results of mathematical model of response to odour

numbers of complaints for his calculations. The respondents were asked to telephone a special line when they wished to complain. On the basis of his results, he identified 'zones' in Rijnmond where odour impact would be greatest to where it would be least. His results for this activity were not shown in his paper.

Clarenburg made the assumption that an overall perception function could be included in his model, which would describe the sensitivity of the population to all odours. When considering how the sense of smell can vary between individuals (see Chapter 2), such an assumption is unsatisfactory. There are, as Punter (1987) points out, also problems associated with using complaints as a means of assessing impact. Although only a few people may experience an odour, they as individuals may experience a severe odour impact. This model fails to take that into account. There may be variations in the rates of complaints due to social differences, individuals may be reluctant to complain, others may do so more readily. Publicity in the media or by pressure groups may affect complaint rates. Once an individual has complained, they are not likely to complain again within a short space of time, for example a few hours or a day. They may be unlikely to complain if the nuisance persists or if it goes away only to return later on (Punter 1987).

A more common means of assessing odour impact is by use of retrospective social surveys. There are many forms of survey, varying in detail and in the type of interview. They can take the form of structured questionnaires, requiring brief answers to specific questions or semi-structured interview surveys where the interviewee is encouraged to discuss at length particular topics of interest.

Regardless of the format of the survey, there are problems associated with this form of data. The most notable of these is recall bias. Such bias can occur, for example if the odour source has had recent media exposure, ensuring it is high profile at the time of the interview (Shusterman 1992). An example of such bias was recounted by Neutra et al. (1991) when they examined various medical symptoms which local communities believed were associated with hazardous waste sites. It was noted that respondents in their survey were more likely to remember examinations of skin lesions for carcinogenicity as if the lesions were actual cancers. The research team referred to this as "value-laden recollection". A control population in a different area showed less biased results.

The attitude of the interviewee and their perceptions of the source and its effects are a further example of a potential source of bias (Neutra et al. 1991, Shusterman 1992). Neutra et al. stated that along with recall bias, a major source for the concerns about health and safety in communities living near toxic waste sites was environmental worry. If individuals or communities are concerned about an environmental nuisance they will be more likely to report problems or complain than others.

Inaccurate recall of the extent of odour pollution and its impact may also occur simply due to the interviewee not recalling events accurately (Punter 1987). However, surveys are a useful means of attempting to assess the impact of odour pollution on an affected community. Bruvold et al. (1983) used surveys in conjunction with ambient air sampling and identified a strong relationship between the concentration of odiferous compounds in the environment and the response in affected communities. This team surveyed four communities living close to sewage treatment plants, two of which were affected by odour pollution from the plants and two that were not. This pattern of impact had been identified on the basis of complaints to the plant operator. They took air samples from the areas selected for the study to measure their H_2S content, this compound being commonly emitted from sewage treatment plants. They surveyed residents of the selected areas, asking them about their exposure to odour and the level of annoyance it caused. The researchers then examined the results of the residents survey together with the air sample results to identify any patterns. The results are shown in Table 3.4.

Location	Odour noticed	Odour not noticed	Mean H_2S concentration $\mu g/m^3$
Pacifica (affected)	**49**	**5**	**5.57 ± 0.5**
Pacifica (unaffected)	**4**	**50**	**1.1 ± 0.7**
Novato (affected)	**19**	**31**	**1.75 ± 0.5**
Novato (unaffected)	**1**	**47**	**‹0.6**

Table 3.4: Results of air samples and social survey carried out by Bruvold et al (1983)

As can be seen from Table 3.4, there was a strong association between high levels of H_2S and individuals perceiving odour.

However a commonly used form of assessment of the impact of an odour source on a surrounding community is that of olfactometry. This involves the use of psychophysical methods to characterise environmental pollution. The different ways such methods are used are discussed in the next section.

3.5 Psychophysical methods and the use of monitor panels

There are different forms of olfactometry used to assess odour pollution.

- The simplest of these methods involves use of observers (sometimes trained, see 3.5.1) to describe odours in the field.
- The next type of assessment involves using dilutions of odour-causing chemicals, in the laboratory, to assess odour intensity.
- Another form of assessment uses subjects, either in the field or in the laboratory to compare intensities of odour-causing chemicals thought to be the source of pollution in the environment with a reference compound, usually *n*-butanol (Shusterman 1992).

There are more complex methods that involve the use of both instrumentation and people. One such technique is 'organoleptic evaluation of gas chromatographic effluents', commonly known as 'smell chromatography' (Shusterman 1992). This process involves diverting part of the output of a gas chromatography column. One part of the output will be used in the instrument's detector for identification. The other will be presented to a subject for identification by sniffing. This technique is frequently used for identification of unknown environmental odours. However in this section, assessment of environmental odour using different types of panel of volunteers will be examined. For ease of reference, the discussion is split into two sections. The first section examines monitor selection and training.

3.5.1. Panel selection and training

Selection of monitors for assessment of odour can be recruited using the methods listed by Punter (1987). These are,

- Distribution of leaflets to pre-selected addresses
- Advertisements in the local press
- Sending letters
- Telephone calls to selected addresses

Methods vary in their level of success in recruiting interested individuals. Punter found that in his research, leaflets were most successful for recruitment, with 10% of individuals contacted coming forward as volunteers. The location of the addresses selected for recruiting volunteers is dependent on the aims of the study. For example, if assessment of odour pollution from a particular source is to be carried out, then the panel should be located in an area surrounding the source. On the other hand if the study is laboratory based and is examining the properties of different odours, then it may not be so important where the panellists come from. Panel size will also be based on the purpose of the study. Panels need not be large, for example, Sweeten and Miner (1993) used a panel of 2 and 3 people for assessing odour intensities at two cattle feedlots (see 3.5.2). Conversely, an investigation into odour pollution by a Californian gas company used a panel of 35 people (Hellman 1975).

However the panel is to be used, in the laboratory or in the field, there are certain activities to undertake during selection before the panel commences work. Researchers may screen volunteers to ascertain if any they are unable, as a result of physiological factors, to detect particular odours (Leonardos 1980). There are different types of tests to identify individuals with or without problems with their sense of smell, such as the Turk-Wittes procedure and the ADL test. Screening techniques, such as the Turk-Wittes procedure, involve tests for intensity detection, identification tests and so-called triangle tests. These tests consist of the presentation of, for example, three flasks, to a volunteer. One of the flasks contains an odour-causing compound, others contain blanks. The volunteer is then asked to identify the flask containing the odour (see 6.3.1). The ADL test (designed by odour analysts at Arthur D. Little Inc. in the United States) referred to above involves selecting individuals with an expressed interest in odour and odour measurement, for example, during a social survey. The only test for sensitivity is to ensure that their sense of smell is not impaired (Leonardos 1980). ADL tests involve "semi-quantitative and qualitative descriptions of odours" (Kendall et al 1974). Volunteers are asked to describe odour intensity and character using four or seven point scales. Each volunteer enters a test chamber containing the odour-causing chemical in a known concentration, sniffs the air three times and then records their results.

There is some disagreement about whether or not panels require training in odour identification. Some researchers have trained panels, such as Sweeten and Miner (see 3.5.2). Experience of an odour can be an important factor in its identification and description of its properties. However, Cain (1980) writes that even well practised subjects have produced variable detection thresholds for butanol. Leonardos (1980) also states that increased sensitivity amongst panellists will result from training. If the objective of using a panel is to select a group of people who have sensitivities to odour that are representative of the general population then training may be counter-productive (Cain 1980, Leonardos 1980). Training may lead to increased odour sensitivity in the panel, which will not reflect that found in the general population. Therefore, in cases where olfactometry is undertaken to assess environmental odours, the levels of training given to panellists, if any, should reflect the experience found in the community being studied. This should include the odour properties related in Section 3.2, such as intensity and hedonic property.

3.5.2 Uses of panels in the field

The way the panel is designed and used depends on the data that is required. Some research has involved taking air samples containing odour-causing compounds and asking panels to test them in the laboratory. An illustration of this is the work of Jones et al (1992), where an olfactometer was used in the field, in this case at cattle depots. Samples were taken from ambient air outside the mobile laboratory containing the olfactometer. Monitor panels can be moved around an odour source, such as a feedlot (see Sweeten and Miner 1993, discussed in 3.5.1 and below). Or they can remain in one place, monitoring from home for example, as with the panel designed by Goldsmith (1973) (see 3.5.1 and below), where industrial odours were the subject of the study. Panellists may be required, if they are monitoring at home, to sniff the air for odours at set times decided by the researchers. This was the way that Goldsmith's panel worked. Conversely, monitors may be asked to sniff for odours when they wish. Panel members may be required to monitor every day or only certain days of the week. The best way to illustrate different approaches to using panels is to use specific examples of different types.

Sweeten and Miner (1993) wished to measure intensity of odour around two cattle feedlots in order to assess the extent of their impact on local communities. An initial examination of the management of the feedlots was made, along with a survey of the surrounding area. Examination of the management of the feedlot included the number of cattle present at the site, cattle housing and means of slurry storage and disposal. Details such as distance to the nearest dwellings and the presence of other possible odour sources were also recorded. Sampling sites in and around the feedlots for the odour panel to use were selected. Sweeten and Miner did not report how the sampling sites were selected. The panels, consisting of two people for odour assessment for one feedlot and three for the other, were trained to determine odour intensity in the laboratory. Training involved the use of an olfactometer containing odiferous air samples diluted with odour free air (see 3.2.2). Panellists sniffed differing samples to ascertain detection thresholds and to enable them to specify the feedlot odour intensity. They were then taken to the sampling points at the two sites and asked to sniff the air. They were then moved further away from the feedlots to successively more distant sampling points. For both feedlots, the odour survey was carried out over one afternoon. Eleven observations were made at one site and thirteen at the other. All statements on odour intensity were recorded by the research team. On the basis of the data obtained, Sweeten and Miner attempted to provide guidelines for acceptable levels of odour intensity.

As an alternative to moving panel members to the source, it is possible to organise a panel in an area adversely affected by odour using local residents. Such a panel was organised in Richmond, California, an industrial area with several industrial odour sources (Goldsmith 1973). The study was undertaken to ascertain the usefulness of using such panels to assess odour impact. Selection of monitors was based on their satisfying several criteria. These were interest in the project, their reliability to make the required number of reports and their presence at home during the monitoring times. There is no mention in the report of the monitors being trained during the lifetime of the panel. Thirty individuals located in different parts of the area were asked to sniff the air daily at 10am, 4pm and 10pm. The monitors were asked to fill out report cards that were collected by supervisors.

These panels, the researchers felt, had produced appropriate information , which met their aims and objectives. The ways that data are recorded can vary according to the nature of the source, what information is required and so on (Punter 1987). Monitors may be required to sniff the air at their home on a weekly basis, asked to make several reports each week or each day. They may have to keep quite detailed diaries of the circumstances when they sniffed the air or simply report if they smelled an odour. Reports can be made by telephone calls by supervisors or completing pre-printed cards. Alternatively, as in the study conducted by Sweeten and Miner, the panels may be taken to the odour source and have their decisions recorded by supervisors.
The list below summarises the points raised in this section:

- Panels may be used in the laboratory or in the field
- The number of times panellists are asked to monitor may vary, from once to several times a day
- Times for monitoring may be set by the supervisor or the panel members may monitor only when they smell an odour

- Recording results may take the form of reporting personally to supervisors, by telephone calls, post-cards or record sheets posted to the supervisor

Some of the factors affecting panel design will be entirely pragmatic. For example, the financial costs of organising and running the panel, the number of people available to supervise the panel and so on. Others, which are more important and have been touched on above, are considerations of the study itself. These factors are discussed in more detail in the next section.

3.5.3 The design and operation of a panel in the community

Practical factors will influence the panel design. These include the nature of the source of odour and how it is thought to affect the surrounding area. Punter (1987) and Maivald (1987) both discuss these criteria in some detail. The panel design will depend strongly on the nature of the source, the odour and its emission as well as the measurement objective. For example, if the source emits odour constantly over time, sampling frequency may be low, at a set time if necessary. Alternatively, if emission is variable, then sampling will have to be more frequent. Consider two different odour sources to be studied. The first source, source A, is an odour source that produces known odour-causing compounds and has technology in place which rigorously controls odour production and release. It emits odour once a week, for example during cleaning of the odour control equipment, at the same time and day every week. The other odour source, source B, emits odour erratically, any time of day, any day of the week. Such an odour source could be a landfill.

The study on source A wishes to measure the pleasantness or unpleasantness of the odour emitted and the difference in intensity with distance. The panel for source A need only be used once a week, on the day of odour emission. The format of the panel may be similar to that used by Sweeten and Miner and described above. The panel may be small, consisting of a few individuals for ease of training and transport. The panellists, could be transported a set distance away from the source and, at regular intervals as they move towards the source, sniff the air and their results recorded by a project supervisor. This procedure may carried out once, as in the case of Sweeten and Miner, or repeated several times, until the required amount of data are obtained.

In this thesis, the panel used for the research activity takes the form of panel B. The study on source B wishes to assess the frequency of occasions when people living at different locations around the source experience its odour. As mentioned above, the source, a landfill site, can release odour at any time for unknown duration. As the frequency and duration of odour events are unknown, the panel must be in operation daily as it is the frequency of events that has to be identified. Another of the objectives of the study is to identify the effects on communities at different points around the source, therefore panel members should be located in those communities. Such effects would include avoiding behaviour such as remaining indoors and closing windows or health effects such as feeling nauseous or annoyed by the nuisance. It is not necessary for them to be taken to the source. It is the impact at the volunteers' homes that is to be addressed. As the monitors can note odours at any time, they must have a means of recording their results. Recording, as Punter (1987) describes, can take different forms. This was discussed in 3.5.2.

The panel for source A would require screening to ascertain that they can smell the odour to be studied, and they may also require training to enable them to judge and articulate odour hedonics and intensity. As intensity and hedonics of the odour are to be measured, the panellists may also be selected for their similarity of sense of smell, for example similar detection thresholds, to ensure consistent results. The panel for source B may be different. It would probably be larger than the panel for source A. This would be the case if the area to be studied around the source is large and or if there is a large number of people affected. If odour frequency is to be studied particular types of people may be used in the panel, namely individuals who are at home most of the time. This was the case in the Goldsmith panel. If the frequency of odour events experienced by the whole community is sought, then this would not be desirable as not all the people in the area will be at home all day. In this case, panellists would have to include individuals who would be absent for certain periods of time. The choice is either to accept all types of individuals, some of whom will have limited times for reporting or to select individuals who are at home all the time at the expense of diversity of response. Again some selection may be necessary to ensure that panel members have no physiological problems with their sense of smell. However, if the exposure of all the community is sought, then individuals with impaired olfactory ability should be included. Their sense of smell should still be tested in order to identify if this influences their reporting patterns, for example missing odours that others detect. Ultimately, panel design is dependent on the information required from the study and the nature of the source and its emissions.

3.6 Conclusion: Methods for assessing odour or odour impact

There are different methods of odour measurement and identification, and assessment or prediction of impact. The methods discussed in this chapter are listed in Table 3.5.

Technical methods	Sensory methods
	Olfactometry
Sampling of ambient air and GC-MS analysis	**'Smell Chromatography' (in conjunction with GC analysis)**
Real time instruments (Electronic nose)	**Examination of complaints**
Dispersion modelling	**Social Surveys - questionnaires and interviews**
	Panels - laboratory based or in the field

Table 3.5: Summary of odour assessment methods

For the purpose of obtaining information on the impact of odour on individuals and communities, it is arguable that use of monitoring panels is most useful. The human nose is the most suitable means of measuring odour, as after all it is the human experience of odour that is being studied. Technical methods of measuring odour are useful if identification of the odour-causing chemical is required or measurement of concentration is needed. However, as pointed out earlier, such methods are not suitable for qualitative assessment of the effects of odour. They would not, for example, establish the intensity of odour experienced by individuals near the source or the hedonic properties of the odour.

If sensory techniques are to be used as part of the process of odour impact assessment, there are choices of approach. These are to use complaints to assess impact, surveys or the use of monitor panels. That complaints are reported may indicate the possibility of a problem with odour pollution. However, complaints are not a reliable reflection of the extent of impact. Certain individuals may be more or less motivated to complain.

It is plausible that an individual may be quite adversely affected by odour yet not report it. The individual may not know who to complain to, or they may wish to avoid conflict or do not know what their rights are. Finally, they may be distracted by other important issues. This may lead the operator of the odour causing process to believe, incorrectly, that there is no problem. Even if an individual makes a complaint, they may be reluctant to report odour again if it occurs quickly after the first incident, so that the frequency of complaints to be lower than the frequency of odour pollution events for this reason. Complaints may arise as a result of 'bad' publicity or action by a pressure group, which may result in a peak, before they fall back to their usual level.

Retrospective social and perception surveys may provide more detailed information but they may be affected by the problem of recall bias, where an individual may report more or less serious impact of odour than actually occurs. This can be overcome by use of questions designed to screen for bias, such as asking about symptoms not connected with the odour source. As with complaints, bias is likely to occur after adverse publicity or if the interviewee is experiencing environmental worry. Additionally, there is reliance on accuracy of recall of odour pollution events, which may also be biased.

There is the alternative of using monitoring panels. They can provide information on temporal and spatial factors pertaining to odour impact. For example, information could be provided on which settlements experience odour more frequently than others. They also include panellists compiling details of odour events as they happen, rather than relying on recall. If the monitoring process is long-term, the effects of publicity can be seen in the frequency of reports made and be taken into account when analysis of the data commences. Of course, as with any other technique for odour assessment, care must be taken in ensuring bias is not introduced by panel design. The major drawback of panels, where panellists are working alone, is the lack of corroborating data to confirm the odour is what they say it is. This is where the use of instrument based techniques is useful and where an interdisciplinary method of odour assessment would have its strengths. Combining measurement of data at source with modelling (using data from the source) and qualitative data obtained by monitoring panels would enable a more complete view of the extent of impact to be obtained.

Chapter 4

The Research Design

4.1 Introduction

As seen from Chapters 2 and 3, the issue of odour and its unwanted presence in the environment has been shown to be complex and difficult to address. The discussion in Chapter 2 revealed there are many factors that affect the ability of the individual to sense the presence of an odour and variation in the response the odour will elicit. These factors consisted of physiological, psychological and behavioural factors. It is the interaction of these factors, which leads to the individual detecting and responding to odour. In Chapter 3, the properties of odour were examined, along with the methods that are used firstly, to assess the response of individuals to odours and, secondly, assess the impact of odour on individuals in the environment. Two groups of techniques were identified, firstly, instrument based techniques and, secondly, sensory techniques. It was pointed out that the two types of method were seldom used together. This may arise due to the nature of the disciplines within which research takes place. The instrument-based techniques are associated with scientific disciplines, such as meteorology and environmental sciences. The sensory techniques are used by social scientists, such as psychologists or sociologists. The simultaneous use of both types of technique would involve interdisciplinary studies, which are not so commonly undertaken. As has been discussed earlier, the merits of such a method are substantial. There is a sequence of circumstances leading to release and dispersion of odour and the response in the population. The fragmented approach of research results in a failure to entirely assess this sequence. An interdisciplinary approach to assessment would provide data on both environmental and social effects, such as affected locations and impact on populations.

One of the research objectives of this study (objective 2) is to identify the variability of response within a population exposed to odour (Section 1.6). It will be argued in this and subsequent chapters that the response does vary and any study endeavouring to assess odour impact must take such variability into account. This variability, it will be shown, arises due to the interplay of the key components first identified in Chapter 2. It will also be argued that temporal and spatial factors will also influence exposure (objective 2). In order to demonstrate that exposure and response to odour can vary, an odour monitoring panel will be used. The reasoning for the use of this technique will be given in this chapter, along with an overview of its design.

In this chapter, the research objectives and questions are examined in greater depth, along with the key components, identified from the objectives in Section 4.2. In Section 4.3, the choice of research techniques used in this study will be discussed. In Section 4.4, background information on the landfill site as an odour source will be presented.

4.2 The research issue and objectives

As stated in Section 1.6, the research question within which the research is placed is

To what extent do physiological, lifestyle and locational factors influence exposure and response to landfill odour?

The research objectives generated by this question are listed below.

- Objective 1: The main objective is to identify attributes affecting the exposure and response to odour within a community. These attributes could then be included in a potential response model that could be used to identify communities and members of communities more or less at risk of exposure and impact to odour. This thesis provides a framework on which such a model could be based. Suggestions are made as to how such a model, when integrated into an interdisciplinary framework, could be used as a tool to assist landfill management, planning and policy regarding environmental impact and nuisance.

This objective is dependent on the two subsidiary objectives below. By addressing them, it should be possible to identify attributes affecting exposure and response and produce a framework within which a response model could be developed.

- Objective 2: To measure and demonstrate the variability in response within a population exposed to odour. It will be shown that variability arises from physiological, psychological and lifestyle factors. These factors will be shown to be important determinants in the individual's experience of odour.
- Objective 3: To measure and demonstrate how temporal and spatial factors also contribute to the differential exposure and response of individuals to odour pollution.

In Chapter 1, the issue of landfill odour pollution was highlighted in some detail. However, it is useful to reconsider that discussion here as the research objectives and activities are based on the issue. Landfill odour pollution is reported as adversely affecting the well being of individuals and their enjoyment of their local environment. Methods for measuring the levels of odour causing compounds and assessing their impact vary (Chapter 3 and Section 4.3) between instrument based techniques and social enquiry. However, each of these techniques has short-comings as well as advantages. One failing common to many of these techniques is a lack of knowledge of the variability of response to odour amongst members of a given population. Without this knowledge, the impact of an atmospheric pollutant, such as odour, on a community will not be fully understood. As discussed in Chapter 2, there are a number of factors that can influence exposure, the ability to detect odour and the response of an individual. Not only this but there are a number of components that must be present before odour has an impact.

The first of these components is the presence and attributes of a source of the pollutant (physical) and secondly, there must be a population to respond to what the source has released. This response involves initially the physical 'equipment' of the individual or their physiological attributes. In the case of odour at least, there are other components involved. They are a psychological response to the source as discussed in Chapter 2 and below. This response, together with the physical response will lead to a behavioural response. This is discussed in greater detail in the following paragraphs. These key components are shown below in Figure 4.1.

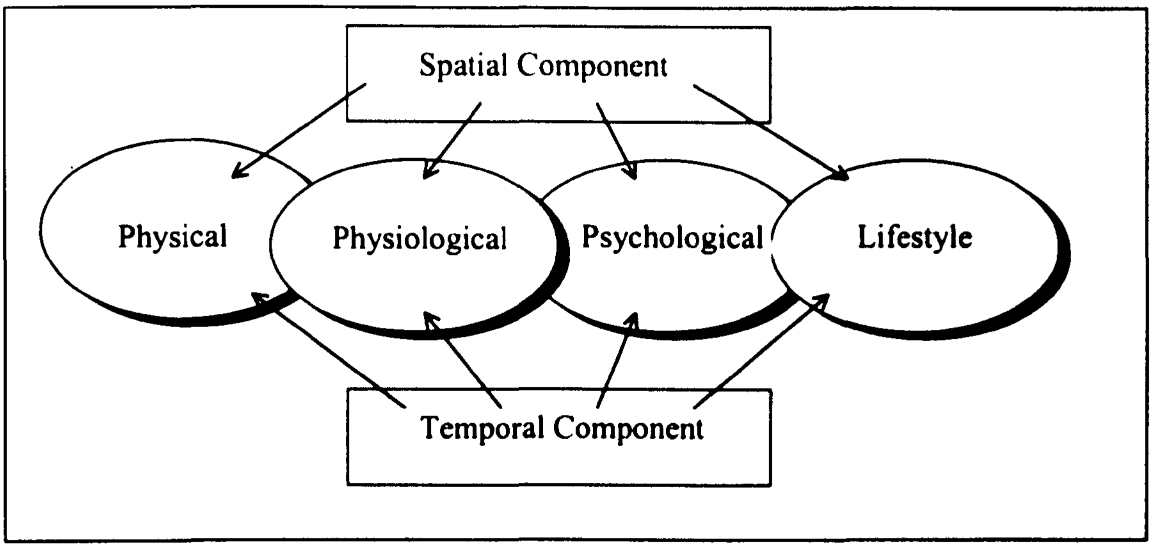


Figure 4.1: Key components in the research

These components are shown as overlapping as they do not operate in isolation but, to varying extents, are interdependent. For example, without the presence of a source there would be no odour. Without the physiological means of detecting odours, there would be no psychological or behavioural response. There are two other components within which the other four components operate. They are the spatial and temporal components that are external to the individual, but affect their exposure and hence their response. They are where the individual is located with respect to the odour source and how frequently they are exposed to an odour plume. These components have a role in influencing response and subsequent behaviour. These components and the framework in which they are found are important elements of the research. It is the recognition of these factors and identification of the linkages between them, which form part of the research objectives of this thesis.

As discussed in Chapter 2, the response of an individual when exposed to odour is based on a number of factors, which can be divided into the physiological and psychological. Physiological factors include the individual's sense of smell, which may be affected by anosmia or specific anosmia, and which may be influenced by age, health, gender and exposure to harmful substances (Section 2.2). Psychological factors affect the personal assessment and response of the individual. These may include the attitude of the individual to the odour source as well as influences from the community (see Section 2.3). These psychological factors were summarised as forming the appreciative system of the individual. As Engen (1972) stated, human observers might, on the basis of their appreciative system, "...emphasise different attributes in different situations or for different sets of odourants". It is the appreciative system that affects the response and behaviour of the individual. Put simply, this means what they will do when they believe they have sensed an odour. This behaviour may vary. An individual may attempt to ignore the odour, or they may carry out some form of avoiding behaviour, such as closing windows or going indoors. They may complain, either to the operator of an odour source or the local authority. Perception and responses to odour are more complex than may first appear. Finally, there is the lifestyle component. This includes aspects such as work patterns, which will influence frequency and duration of occasions when an individual can be exposed to odour.

One of the major research objectives for this thesis is to examine the linkages and relationships between the different components outlined above. Research into 'odour', as discussed in Chapters 2 and 3, can be sub-divided into instrument based or sensory techniques. There are some techniques that could be said to overlap, such as combined gas chromatography and olfactometry. Gas chromatography and mass spectroscopy are classic analytical techniques used to identify and quantify odour causing compounds found in ambient air samples. Occasionally, this approach may be integrated with the use of human subjects who sniff the samples as they pass through the GC column in order to describe the sample's odour properties. By doing this the properties of the odour causing compound can be identified, quantified and described. However, the sample is not judged in the context where it may cause annoyance, that is in the environment surrounding the odour source by the population affected. Other methods are often used in isolation from the environment. Dispersion models are used to estimate the concentrations of odour causing compounds at distance from the source. Again, as with other laboratory based techniques, there is no way of knowing the extent of annoyance caused. Dispersion models assume Gaussian distribution of pollution in the mean wind direction. This may not be the case if the wind is veering markedly or if eddying in the odour plume causes concentration fluctuations along its length. As mentioned earlier in the thesis, there are other problems inherent in the use of dispersion models that may influence their effectiveness for use in landfill odour pollution studies. This is examined in Section 4.3. Alternative methods involve social enquiry techniques, such as interviews and surveys. These are frequently undertaken without testing respondents' sense of smell or examining their background for factors that affect odour perception. A more complete discussion of the above is given in Section 4.3.

It is only possible to begin to understand odour impact (and possibly the impact of other pollutants) on individuals and communities, by adopting an interdisciplinary approach. Such an approach involves recognition of the components of the issue identified above and attempts to take them into account. This is achieved by adopting an approach that involves assessment of an individual's olfactory ability as well as their experience of odour exposure and annoyance in the context of the environment where annoyance occurs. An attempt will be made to explore how the attributes of an individual affects their exposure and detection of odour. This links to research objective number 2, which was to demonstrate how variable the response within a population can be. The third research objective, on how spatial and temporal factors can affect odour exposure is also addressed by this enquiry. The questions arising from these two objectives, which the research seeks to answer are the following:

- How do personal factors, such as age or health affect the exposure levels of odour an individual can experience? It is known that such factors affect detection and identification of odour (Chapter 2).
- How does an individual's lifestyle and behaviour influence their exposure to odour? Such behavioural factors, again are thought to affect exposure to odour and the response to it (Chapter 2).
- Go on to attempt to relate this information to spatial and temporal factors; where an individual is in relation to the odour source. Individuals downwind in the direction of the prevailing wind from an odour source may be expected to be exposed to odours more frequently than individuals located upwind (Chapter 3).

With the information obtained through the research activity, it will become apparent that the response and exposure to odour can vary between individuals with differing physical attributes, with different lifestyles and at different locations. With this knowledge, the argument for an interdisciplinary method becomes much stronger, as the assumption that exposure and response should not vary greatly in the population is shown to be incorrect. As was pointed out in Chapter 1, research into pollution impact is frequently carried out to assess impact on people. An interdisciplinary method would facilitate inclusion of population response, which would therefore provide greater insight into odour impact where it occurs, namely, amongst affected communities. Understanding of the variability of response and the importance of identifying how temporal and spatial factors can influence odour exposure can be used in a second way. This is to define limitations of current methods.

4.3 The choice of Research Techniques

The basis of the research is to identify the importance of aspects of odour detection and response, discussed in Chapter 2. They interact with each other and with spatial and temporal factors, dictating whether or not an odour is detected and what the response to it will be. It should be noted that an odour event, that is the occurrence of an odour in the environment, will have certain characteristics. An odour, when in the environment will have intensity levels, hedonic qualities and character. It will also be present for a period of time and may recur (see Chapter 3). Whilst it is in the environment, the odour may be sensed by an individual who will respond to their exposure in a particular fashion. In order to clarify this relationship, it is necessary to obtain data in the field using a form of monitoring panel. It will be remembered from the discussion in Chapter 3, that there are laboratory- and field- based methods of studying different aspects of odour. In the following discussion a summary of the techniques for odour assessment is presented and then the reasoning behind the choice behind the use of a monitoring panel as being appropriate for the research.

There are, as discussed in Section 3.3, well-established analytical methods of obtaining information on the chemical constituents of odour samples, notably gas chromatography-mass spectroscopy. Use of these techniques enables a chemist firstly, to identify the chemicals present in a sample of odour bearing air and, secondly, estimate the concentrations of the chemicals identified. As some odours can produce a response in subjects at 10^{-9} ppb. (vol.) (Cheremisinoff 1992), a preconcentration step may be required and is carried out prior to analysis (Dravineks 1975). Frequently, as related by Shusterman (1992), these analytical procedures are combined with trials using human volunteers as sniffers to describe the odour's properties, such as intensity and hedonic qualities. This is referred to as the analytical/sensory approach by Dravineks (1975). He describes a method that involves the use of a gas chromatography column to analyse the constituent chemicals of an air sample, but which also has a sniffing port attached. Use of this port enables a subject to smell the odours constituent chemicals as they leave the column. By doing this it is possible to obtain quantitative information on what odiferous chemicals are present and how they smell to the subject. This is referred to as 'smell chromatography' by Shusterman (1992).

Apart from chemical analytical processes, there are real-time technologies that can be used to monitor odours, such as the electronic nose or multi-gas sensor system (Ramalho, Regoui and Kirchner 1997). These technologies can be used at the odour source and can be used to detect odours as they are released. Alternatively, dispersion models may be used and, indeed, frequently are used in odour impact assessment (see Van Harreveld 1997). As highlighted in Section 3.3, there are limitations associated with these models which, in the case of landfill odour studies, could be quite important. It is important to know details of pollutants emitted, their rate of emission and the points of emission. As will be referred to in Section 4.4, the landfill site may or may not be emitting any number of odour causing compounds; it may be releasing odours from one or more points, and the emission rate may not be known. Emission will be at or near ground level, unlike other sources such as industrial stacks, which may affect the estimates calculated by the model. Finally, as with other technological methods, there is no qualitative information, such as length of exposure, times of exposure, or odour hedonics, provided with the use of dispersion models.

Other laboratory-based techniques involve the use of volunteers who sniff odour-bearing air samples taken from an odour source. These are usually presented to the volunteers via some form of an olfactometer (see Section 3.2). There are many designs of olfactometer, but it is a device that simply delivers odour samples to volunteers via a sniffing port. The samples can be diluted by the researchers to desired levels and the volunteers are asked to state if they have detected an odour or not.

There are drawbacks to using these differing technology-based approaches. The techniques that are used in the laboratory involve the use of samples taken from emissions at the odour source. Therefore care must be taken ensure that samples are taken at the correct time when odours are being released. This may be difficult to determine when assessing odour emissions from landfill sites, as it may not be immediately obvious if the site is emitting odour and where it is being released. Odours may consist of more than one compound and they may vary in concentration, affecting the odour's qualities, such as its hedonic properties. Mixing with non-odorous air will dilute the odour's concentration, which again may affect its hedonic properties. Diaper (1987) describes how an odour's properties vary as they travel away from their source through the atmosphere. The effects of this fluctuation, which may affect the impact of the odour, may not be detectable by laboratory analysis. Additionally, it should be remembered that samples are analysed in the laboratory away from the source and the population affected by odour pollution. Therefore characteristics of odour pollution events, such as frequency of events and their duration, as well as the circumstances in which individuals detect odours, are excluded from the study. These factors are very important in understanding the nature of exposure to odour and response that a population will experience. It is also tempting to use these techniques uncritically as they produce quantitative data, which is straightforward to understand and use. As Hobbs (1995) states, use of quantitative methods avoids the difficulty of addressing 'the subjective human response'. However, the subjective human response to odour is the crux of the problem. If humans had no sense of smell or if they were located away from odour sources, there would be no problem and no need for odour research. Any technique that is solely dependent on instrument based techniques and which does not take into account the response of individuals to odour at the point of impact is not addressing the effects of environmental odour pollution. There is a need to address the problem of the impact and perception of odour pollution in its context and that is in the community.

In an effort to study odour impact on communities, researchers may use one of several approaches. These are as follows,

- To study complaints made to managers of odour producing processes.
- To undertake community surveys
- To arrange panels of odour monitors in the community.

In Chapter 3, some authors noted that reported complaints were an accurate reflection of the impact of odour on communities (Bruvold et al. 1983, Clarenburg 1987). They stated that the distribution and number of complaints matched the extent of odour pollution in the community. Other authors disagree with the idea of complaints accurately reflecting the extent of odour pollution.

Punter (1987) is critical of methods that use complaints as a means of assessment of odour impact. It is worth summarising the points made in Chapter 3 again here. Firstly, Punter pointed out that although only a few people may be exposed to an odour, and produce few complaints, the odour impact may be very severe. Secondly, differing social groups may be more or less inclined to complain. Thirdly, publicity relating to an odour source may affect complaint levels. Finally, once an individual has complained they may be less likely to complain again, even if the odour is persistent or goes away and returns later. There is another point raised in Chapter 2, which is relevant to complaints as well as surveys, and that is the attributes of the individual and how they influence exposure levels. For example, Dodd (1980) explained, one person's sense of smell may vary from his or her neighbours and therefore their ability to detect odours and hence their response may vary also. Reliance on complaints data will lead to these subtleties in response being missed by researchers.

A more common means of attempting to assess odour impact is by use of surveys. This usually involves the use of questionnaires or interviews. As with reliance on complaints data, there are drawbacks to this means of assessment. Selection of respondents is an important factor, as is the use of suitable questions that will not lead to ambiguous answers or prompt respondents into providing answers they think are required. Thu and Durrenberger (1995) chose the information they required, identified their target group of respondents, individuals actively involved in campaigning against a livestock facility, and they designed their method of obtaining information (open interviews with groups of respondents). It is important that surveys take into account such factors otherwise the information obtained may not be what is needed. A major advantage of surveys is that they can provide useful background information on the population being studied. This should include details on the respondents' age or lifestyle, which can influence an individual's experience of odour. If this data are not known then it is difficult to know how conclusions about odour pollution impact could be drawn. For example, it may not be known how often a respondent is at home or if the respondent has health problems affecting their sense of smell. These factors may affect their exposure and response.

Another method of obtaining information relating to levels of exposure to odour, odour-monitoring panels, can be used (see Chapter 3). These can be designed to include assessment of a volunteer's sense of smell and training if it is considered necessary. The panels can take different forms. Firstly, they can consist of volunteers taken to an odour source and asked to sniff the air at specific locations around the source. Such a panel was used by Sweeten and Miner (1993) in their work on assessing the intensity of odour produced at livestock feedlots. Conversely, they can stay at a particular location, for example their home, and sniff the air for odours (see Goldsmith 1973). Use of a panel has the advantage of providing information as the odour is perceived directly rather than relying on recall and would provide more accurate information if the frequency and duration of odour pollution were the important issue. It would also be suitable if researchers wished to identify those members of the community most likely to be affected by odour.

Use of a panel is the most appropriate method of obtaining the qualitative and quantitative data necessary to establish the relationships of the components identified in Figure 4.1. Laboratory methods, both instrument based and sensory techniques would not be suitable. They would not provide information on the number of times a community would be exposed to an odour or the circumstances in which that exposure would occur. A similar failing would be encountered by use of dispersion models (see 3.3.2). It may be possible to generate estimates of odour concentration at distance from the source, but these estimates provide no information on the extent of the nuisance generated.

The use of a panel would overcome problems associated with reliance on complaints and social surveys. Reliance on complaints data as an indicator of the extent of odour pollution is not satisfactory. The level of complaints arising from a settlement may not be an indicator of levels of odour pollution. Individuals have differing propensities to complain or to complain more than once. Additionally, from the point of view of this research, complaints data does not have sufficient detail to identify the relationship between the components identified in Figure 4.1. A social survey would provide information of sufficient depth, but would be subject to problems common to all surveys. These include recall bias and inaccurate recall of information (see Section 3.4). The use of a social survey was appropriate for the research conducted by

Hadfield (1997), where she wanted to elicit the concerns and agendas of respondents in terms of health and asthma, traffic pollution and traffic policy. She had to examine perception of pollution from a dispersed source, traffic, across a wide area. She needed a 'snapshot' of perception found amongst the public. In this research, the impact of odour from point sources, two landfills, on a specific population was studied. The area and population were therefore more clearly defined. Also, in order to identify the experience of exposure to odour on a daily basis over a period of time, the use of a panel is more appropriate. It provides detailed information on events as they occur. An additional problem, common to both use of complaints and surveys is that, unless some form of olfactory testing takes place, there is no means of knowing the nature of the respondent's olfactory ability.

Finally, it should be stated why, during the course of this research, a dispersion model was not used to model the extent of odour pollution in the Marston Vale, the area involved in this study. Such models have been used to predict odour impact from landfill sites in the past (see Van Harreveld 1997). Indeed, at the outset of this research, an atmospheric dispersion model, ADMS, was used and its results assessed. Data related to the source characteristics, materials emitted, weather conditions and topography of the area of interest are required to form the data input. The model will then calculate dispersal patterns, providing predictions of areas affected and the length of time they will be affected. However, there are limitations associated with such models, largely related to data used for and generated by such studies. When ADMS was used, such limitations became apparent. These limitations have been referred to earlier (Section 3.3), but are highlighted again here. The data required for using such models and that derived from them are summarised in Table 4.1.

When examining landfill odour pollution, some of these requirements may not be satisfied. Information relating to odour emissions may not be available. It will become apparent from information in Section 4.4, that the landfill is a complex odour source, particularly when compared to an odour source such as a brickworks.

Data input	Calculation	Data output
Emission data: Odour causing compounds emitted Emission rate Location of emission point/area Times and duration of emission	**Model will contain a set of parameters included by designers.**	**Prediction of area(s) affected.**
Meteorological data		**Length of time areas affected**
Topography		**Predictions of concentrations of odour-causing chemicals**

Table 4.1: Data that forms dispersion model input and output

The landfill covers a wide area and contains a variety of odour sources. These include raw waste, decomposing wastes, gas extraction systems and treatment plants. The location of some of these sources will be known, but others, such as decomposing wastes, will not. A cocktail of odour causing compounds will be released at unknown emission rates. As a result of points of emission being unknown, it would be difficult to identify and measure them. Compare this to a brickwork site, where the pollutants can be identified, emission rates measured and sources identified. Collection of data from such a site would be more straightforward. The meteorological data used with such a model will probably be averaged, for example hourly averaged, resulting in any fluctuations in wind direction or speed being missed. The properties of the wind can be vital in the dispersion and resulting exposure to pollution. Hourly averaging may result in brief periods of exposure being missed. The effects of topography on dispersion may also be missed, although some dispersion models can take into account complex terrain and the effects of valleys, hills, plains and built up areas. However the complex interaction of weather and terrain may not be fully realised. The problems with this data input may affect the calculations of the model. There may also be limitations with the model itself in the range of parameters it may contain. For example, it may be designed for single point sources or stacks, such as those found at a brickworks. It may not be able to make satisfactory predictions from an area source at ground level such as a landfill. The output also may be limited. As stated above, the areas likely to be affected by pollution will be identified and the number of hours the pollutant will be present calculated. However, there is no estimation of the level of exposure or "dosing" found amongst the local population. This is ultimately the reason why the study is undertaken in the first place.

These limitations became apparent when ADMS was used. There were no data on landfill odour emissions available, such as compounds being emitted, times and duration of emissions. The point or points of emission were unknown and meteorological data used were not local to the Marston Vale, where the landfill sites of interest are located, but were recorded 40 miles away. The output indicated concentrations downwind of the point source, but as referred to above gave no indications of times and duration of odour being present in the environment. There was no indication on how the components identified in Section 4.2, were implicated in an odour event. Use of a dispersion model could not provide information on how variation in the qualities or attributes of individuals may contribute to exposure to odours. Neither was there any indication of how these attributes interact with spatial and temporal factors to produce an odour event. Therefore, the questions surrounding the importance of the attributes and factors could not be answered by use of a dispersion model and so it was not used further in this research.

There are limitations associated with the use of dispersion models that may make their use in landfill odour studies not so straightforward as say studies in brickwork pollution. This does not mean to suggest that such studies are worthless. Indeed this is far from the case and is why the interdisciplinary method proposed in Chapter 1 recommends the use of dispersion models. It is proposed in this thesis for dispersion models to be used in tandem with a population response model developed from the research activity. This would result in identification of areas likely to be affected by landfill odour pollution and the extent it impacts on communities or individuals.

The details of the design of the panel are introduced in Section 4.5 and are discussed further in Chapters 5 and 6. Additionally, the case study, that of landfill odour, is discussed. Firstly, it is necessary to provide background information on landfill processes and management, and release and dispersion of odour from such sites. This is undertaken in Section 4.4 below.

4.4 Choosing a Case Study: The landfill site as an odour source

Odour pollution produced from landfill forms the case study for the research. This section examines, briefly, the landfill as an odour source, namely site operations, decomposition processes; odour production; odour control techniques, and release, dispersion and behaviour of landfill odour in the environment. The problems the landfill poses for operators and regulators, as well as for the surrounding community, contain all the elements of an appropriate case study. It will become apparent that landfill odour is a complex phenomenon, in terms of its production and release, its chemistry and its behaviour. This poses serious difficulties for landfill operators and regulators in their efforts to control emissions and their impact. This section provides background material for the following section in examining landfill odour pollution and its assessment in the Marston Vale in Bedfordshire.

4.4.1 The landfill as an odour source

Waste disposal sites over 5000 years old have been found in many parts of Europe (Senior 1990). The roots of the modern landfill found in Britain today lie in legislation dating from the 1930s. Regulations stipulated several new steps should be taken in waste disposal. Firstly, controlled tipping of wastes at landfill sites should take place in layers no more than 6 feet deep. Secondly, cover should be applied to exposed waste surfaces within 24 hours of emplacement. Thirdly, that screens should be erected around the site margins to prevent the escape of litter from the site (Senior 1990). These actions were taken to prevent problems such as waste fires, infestation by vermin and flies and the escape of litter and that had occurred up to that time. It was also hoped that the use of daily cover would prevent the escape of odours from the site. However, despite these and later regulations, the introduction of new technologies and management techniques and, overall, a greater professionalism on the part of operators and regulators, odour pollution still occurs.

The reasons for these problems with landfill odour arise from the fact that waste can be inherently odorous. It consists of materials that will decompose, releasing odiferous chemicals into the environment. The landfill site will contain substantial quantities of this material spread over a large area exposed to the environment, and which may take decades to finally complete decomposition. Therefore the operator is trying to control odour emissions from materials that will naturally release odour, which are initially exposed to the open air and will permit passage of odour-causing chemicals from lower down in the waste to the surface. Not only does the operator have to deal with waste odour on a daily basis, but also has to deal with the problem over the long-term.

Refuse decomposition processes leading to evolution of bulk and trace landfill gases are understood in general terms (Farquhar and Rovers 1973, Senior and Balba 1990, DoE 1991). It is known that waste breakdown in stage I is initially aerobic in nature, that is it occurs in the presence of oxygen. Decomposition processes involve the activity of groups of microorganisms and invertebrates. These include genera of bacteria such as Bacillus, Pseudomonas and Achromobacter; fungii such as Aspergillus, Fusarium and Penicillium, and invertebrates such as mites, millipedes and nematodes (Senior and Balba 1990). When the oxygen present in the waste is consumed, waste breakdown becomes anaerobic in nature and stages II, III and IV are reached. Initially, breakdown is carried out by facultative anaerobes and finally, by obligate anaerobes, including *Clostridium* sp. and *Syntophomas* sp (Senior and Balba 1990). Facultative anaerobes are organisms that tolerate the presence or absence of oxygen; obligate anaerobes can live only in an oxygen free environment (Crawford and Smith 1985). The length of time taken for waste breakdown to reach stage IV can vary. Farquhar and Rovers (1973) estimated the time taken varies between 180 and 500 days. During the different stages of breakdown, different by-products are released. These include gases that are produced in varying quantities. During the aerobic phase the major gaseous by-product is CO_2, during the anaerobic phase CH_4 and CO_2 are released. The bulk gases emitted by landfills are shown in Table 4.2.

Bulk Gases	Typical value (% volume)	Observed Maximum (% volume)
Methane (CH_4)	**63.8**	**88.0**
Carbon dioxide (CO_2)	**33.6**	**89.3**
Nitrogen (N_2)	**2.4**	**87.0**
Oxygen (O_2)	**0.16**	**20.9**
Hydrogen (H_2)	**0.05**	**21.1**

Table 4.2: Bulk Gases found in Landfill gas
(From DoE Waste Management Paper Number 27: The Control of Landfill Gas 1991)

Although these bulk gases are odourless, they may be contaminated by odour-causing gases, which form only 10% of the total quantity of gas released, but are responsible for all the odour (DoE 1991). These minor constituent gases are shown in Table 4.3.

Landfill operators not only have to deal with odour from raw waste, but also from gases released from emplaced wastes. Odour may be produced from other sources at the landfill, such as leachate, (liquid by-product released from wastes), and any chemical treatment plants or lagoons that may be present.

It is also known that there are many odour-causing chemicals released by landfill wastes (Young and Parker 1983, Young and Heasman 1985, DoE 1991, Rettenberger and Stegmann 1991). Odour-causing chemicals include limonene, amines, such as trimethylamine, benzenes, xylenes, alcohols, such as butan-2-ol and esters.

The type of compound and their quantities are thought to vary with a number of factors. These include waste age and the stage of breakdown reached, waste type and co-disposal (where liquid and solid wastes are disposed together), pre-treatment and site factors. Young and Parker stated in several papers (1983, 1984, 1984) that they believed that the critical factors in odour production were waste age, decomposition stage and pretreatment. They reported that younger wastes in early decomposition were likely to produce compounds that were more odorous. These include oxygen and sulphur bearing species, such as mercaptans. Pretreatment such as shredding may increase odour production levels due to an increased waste surface area on which bacteria can act. Baling will reduce odour production levels for the opposite reason, which is reduced waste surface area. Watson-Craik et al (1992) stated that odour potential could be greatest at co-disposal sites, where industrial wastes containing chemicals such as toluene and trichloroethylene are disposed with domestic ones. Young and Parker (1983) reported that this is not an important factor. In other articles, such as Farquhar and Rovers (1973) and Senior and Kasali (1990), no references were made to co-disposal contributing to overall odour impact. However, Farquhar and Rovers (ibid) and Young and Heasman (1985) report that landfill conditions can be very site specific and, possibly, what is observed at one site may not occur at another. There is some agreement about the presence of particular materials, such as heavy metals and certain organics, which inhibit waste breakdown and hence odour production levels may fall.

Minor gas	Formula	Molecular weight	Odour quality and hedonic tone
Butyl benzene	$C_6H_5C_4H_9$	134	no odour
Butan-2-ol	$CH_3CHOHCH_2CH_3$	74.2	sweet, pleasant to neutral
Butyl acetate	$CH_3COO(CH_2)_3CH_3$	116.2	sweet, pleasant
Di-methyl amine	$(CH_3)_2NH$	45.08	fishy
Dimethyl sulphide	$(CH_3)_2S$	62.3	decayed vegetables
Ethyl benzene	$C_6H_5C_2H_5$	106.7	
Ethyl butanoate	$CH_3CH_2CH_2COO$ C_2H_5	116.6	
Hydrogen sulphide	H_2S	34.08	rotten egg odour
Limonene			lemon
Methyl mercaptan	CH_3SH	48.11	sulphidy, pungent decayed cabbage
n-propylbenzene	$C_3H_7C_6H_5$	120.9	
Propyl propionoate	$CH_3CH_2COOC_3H_7$	116.16	
Trimethylamine	$(CH_3)_3N$	59.11	fishy, pungent
Xylenes		106	sweet

Table 4.3: Some minor components of Landfill Gases
(From Verschueren 1977)

As a result of the large number of chemicals which can potentially cause environmental odour that are released from the landfill sites and their varying quantities, the landfill operator has to deal with an odour that varies in character. This may cause difficulties with trying to identify what the source of the odour is and attempts to control it.

4.4.2 Factors affecting landfill odour emissions

There are several groups of factors that will influence landfill emissions. These include the chemical properties of the odour-causing compounds, the conditions within the landfill and climatic influences.

The characteristics of odour-causing compounds, which affect whether they are released or retained within the landfill, are solubility in water, sorptive qualities, vapour pressure and molecular weight. If the compound is water soluble, it is likely to retained within fluids in the waste or within leachate. If it is not soluble it may be retained within wastes or released (Mackay and Stiver 1991). If the chemical is easily adsorbed, for example on to clay particles, mineral particles or organic materials, it is more likely to be retained by the wastes or cover material. The vapour pressure, defined by Baker and MacKay (1985) as its solubility in air, indicates how volatile the chemical is. If it is volatile, it will evaporate easily (Mackay and Stiver 1991). Many landfill odourants, such as ethyl butanoate and butan-2-ol, are highly volatile. Low molecular weight compounds will volatilise more easily than those with high weights. Again, many landfill odour-causing chemicals, such as methyl mercaptan have low molecular weights. The mixtures of chemicals that are released from landfill sites may affect odour qualities (Haring 1974).

Conditions within the landfill will also affect odour emissions. These include substrate moistness, temperature and the type of cover material. Ordinarily, there is an optimum level of waste moistness when the potential for odour release is greatest. Too much or too little moistness will impede odour release, as pores facilitating release of odour will be blocked or more sites for adsorption will be exposed (Baker and Mackay 1985). Therefore chemicals which are easily adsorbed will be retained within the waste mass. It could be argued that wastes should be kept deliberately excessively dry or wet by operators as a means of controlling odour release. However, this may adversely affect waste breakdown processes in general, which in turn would affect the aim of a stable waste mass. Elevated temperatures within the waste increases vapour pressure, which in turn increases volatilisation rates and enhances the release of odour causing chemicals (Baker and MacKay 1985). The cover material will impede odour release if it is of satisfactory depth, has low porosity and has a high clay or organic content as it would "trap" odour causing chemicals (Baker and Mackay 1985).

The landfill operator has not only to deal with the landfill itself when attempting to control odour. As mentioned above, the landfill site is interactive with the local physical environment. Climate is an important factor in landfill behaviour and emissions of odour. Climatic factors affecting emissions are temperature, atmospheric pressure, infiltration by water and air turbulence at the surface. These factors may operate singly or at the same time (Mackay and Stiver 1991). The existence of a temperature gradient between the wastes and the atmosphere will increase emissions (Baker and Mackay 1985). A large gradient between a warm landfill and a cool surface enhances thermally induced diffusion of volatile compounds into the atmosphere (Baker and MacKay 1985). Similarly, fluctuations in atmospheric pressure may act like a pump, and push gases out of the landfill. Movement of water can result in odourants being brought to the surface of the waste. Water can block adsorption sites, permitting odourants to escape. The mass flow of water in waste can result in upward movement of chemicals. As water evaporates at the surface, more water carrying chemicals is drawn up to the surface from lower down in the waste. Once at the surface, the water and the chemicals it brought to the surface can evaporate (Spencer and Cliath 1977).

4.4.3 Transportation of odour from its source

Once at the surface, odour-causing chemicals can cross the thin laminar layer of air running over the waste surface, into the turbulent layer of air above. The laminar layer is, at, most a few millimeters deep and its flow is smooth and non-mixing. Its depth is influenced by surface roughness and wind speed (Oke 1992). Over smooth surfaces or on very windy days the layer will be thin or possibly absent (Oke 1992). Chemicals will cross this layer by molecular diffusion. Evaporation into still air will be slower, than on windy days but will still occur (Shen and Tofflemire 1980). Once through the laminar layer, the chemicals move into the turbulent or constant flux layer (Oke 1992). Here they may form a pollution plume that could be described as an isolated column of gases, vapours or particulates produced by processes at a source, which are chemically or physically distinct from the surrounding air. A plume may not have a chance to form if wind speeds are high, the chemicals may be diluted or dispersed instead. If a plume does form, it may be transported away from its source. If this occurs, then individuals living downwind of the source's origin may be exposed to the chemical contents of the plume. When this happens, communities are exposed to odour pollution.

Whilst being transported, the plume will be diluted by mixing with non-odorous air. This eddying action has two results. Firstly, the odour concentration may vary along the plume's length, which means that the odour impact may also vary as the plume travels to a particular location (Pagé et al 1997). Secondly, mixing will ultimately dilute the odour concentration to a point where it is no longer detectable and therefore will no longer have the potential to cause annoyance. The odour-causing compounds within the plume will also undergo physical or chemical changes, which will also affect the plume's annoyance potential. For example, the compounds will decompose, or break down, into smaller molecules or into constituent atoms. Again, these actions will affect the plume's odour.

4.4.4 Techniques to control landfill odour

There are methods available to control landfill odours. One is the use of daily cover material, where the freshly deposited waste is covered at the end of the working day (Crawford and Smith 1985). It can consist of any non-putrescible material, such as sacking, builders' rubble or compost. How effective each of these cover materials are as a means of control is not clear. If the material has sorptive qualities, odour-causing chemicals may bind to it. If it does not have this property, then chemicals may escape through it. When the landfill is filled to capacity, it is covered with a permanent cover, to prevent, amongst other things, uncontrolled escape of gases to the atmosphere. Control of gases produced during waste decomposition is usually done via a gas extraction system. The gases are drawn through the waste via a pipe network, brought to the surface and burned off. There are concerns that this flaring off of gases may not be effective at burning all gases fully, resulting in the occurrence of odour pollution (ENDS Report 1998). The pipelines remain in the wastes after site closure in order to extract gases evolved during the final stages of decomposition. The final means of controlling odour impact is the use of masking agents to disguise the odour. Cheremisinoff (1992) writes that chemical sprays can control odours. On the other hand, Summer (1971) writes that masking agents are ineffective and their use consists of 'adding a stink to hide a stink'.

The use of cover material and gas extraction systems both attempt to prevent odour release from the waste. Masking agents are the only attempt at preventing odour pollution impacts after release and are attempts to disguise odour rather than controlling it.

4.4.5 Summary of Section 4.4

- Waste breakdown leads to production of many different potential odour-causing chemicals.
- Processes within the landfill and external factors will influence when and where odourants are released.
- The odourants released into the environment can then be dispersed through the environment and be sensed by members of the local community.
- The operators face many difficulties when trying to manage this complex phenomenon. They may not fully understand the processes operating within the waste at any one time and, it is arguable, how much they can control these processes. They may not know precisely what kind and quantities of odourants are released into the environment. They also may not know when odours are emitted or from what places on the landfill site.
- Factors, such as the climate, which are out of the operator's control, will affect landfill odour emissions and where those emissions travel in the environment.

Landfill sites fall into a group of odour sources that are open to the environment and are, to varying extents, difficult to control. Other sources in this category include sewage treatment plants or agricultural sources such as pig farms. The odours from these sources are difficult to manage because of the complexity of their of behaviour and their interactions with the environment.

4.5 Research Activity

The background and details of the research activities undertaken for this thesis are as follows. Table 4.4 summarises these details.

(It should be remembered that a questionnaire survey and a pilot study using a monitor panel were carried out prior to the research activity for this thesis. However, these earlier activities formed much of the basis for this research and are referred to frequently throughout this thesis.)

Date	Activity
1993	**Questionnaire survey carried out in Marston Vale (see Chapter 5)**
1994	**Pilot study panel formed and starts to produce reports**
Summer and Winter 1996	**Inspection of data from pilot study panel. Leads plan of research activity, including formation of new panel***
Spring 1997	**New style panel introduced to facilitate research for this thesis***

* activity undertaken during the course of the research for this thesis

Table 4.4: Summary of research activities into landfill odour pollution undertaken at International Ecotechnology Research Centre 1993 to 1997

4.5.1 Pilot study

In 1994, prior to this thesis, an odour-monitoring panel was formed in the Marston Vale area of Bedfordshire (see Chapter 5). This area contains two landfill sites that had generated odour annoyance in the local community. The monitors were asked to sniff the air at their homes on a daily basis and state if they had smelled an odour and try to identify it. The data produced by this panel were then analysed. Firstly the data were examined for the following,

- The times of reports
- The locations of reports
- The numbers of reports relating to different odour types

The data were analysed on the basis of monitor type, for example gender, age and occupation. This was done in order to establish if personal attributes were related to odour reporting. It became apparent that not enough information was known about the background of the monitors, for example if they smoked, the length of time they were at home and their opinion of different aspects of their locale. This problem is discussed further in Chapter 5. Despite this, sufficient insight into monitoring behaviour was developed which led to the development of a simple model of response, an "odour reporting tree".

4.5.2 The odour monitoring tree

An overview of the tree is shown in Figure 4.2 and is developed further in Chapter 5. The tree shows how different components were identified which affect the exposure of an individual to odour and how they relate to each other. They are loosely grouped together as follows;

- The Spatial/Temporal component, which include where the individual is in relation to the source and times and lengths of time when they may be exposed to odours.
- The Lifestyle component, including smoking habits and employment pattern.

- The Psychological component which includes opinion of the local area, including landfill sites.
- The Physiological component including age, gender and health.

The tree was designed to illustrate what circumstances and qualities occur which lead to an individual, in this case a panel member, detecting the presence of an odour or not. On the basis of the data analysis and development of the tree, the next stages of the research activity were developed. It was decided to re-design the pilot study panel, to change how data were recorded and obtain additional information on the monitors. As briefly mentioned in 4.5.1, very little information was known about the monitors. Their ages, gender, occupations (with some limitations) and addresses were known. Other information, such as smoking habits, health and employment pattern were not. These details related to the attributes examined above and in Figure 4.1. So, for example, the location of the home of the monitor was a spatial factor; their health a physiological one. Inspection of the data from the pilot study indicated that at least some of these unknown details may have influenced the reporting patterns seen.

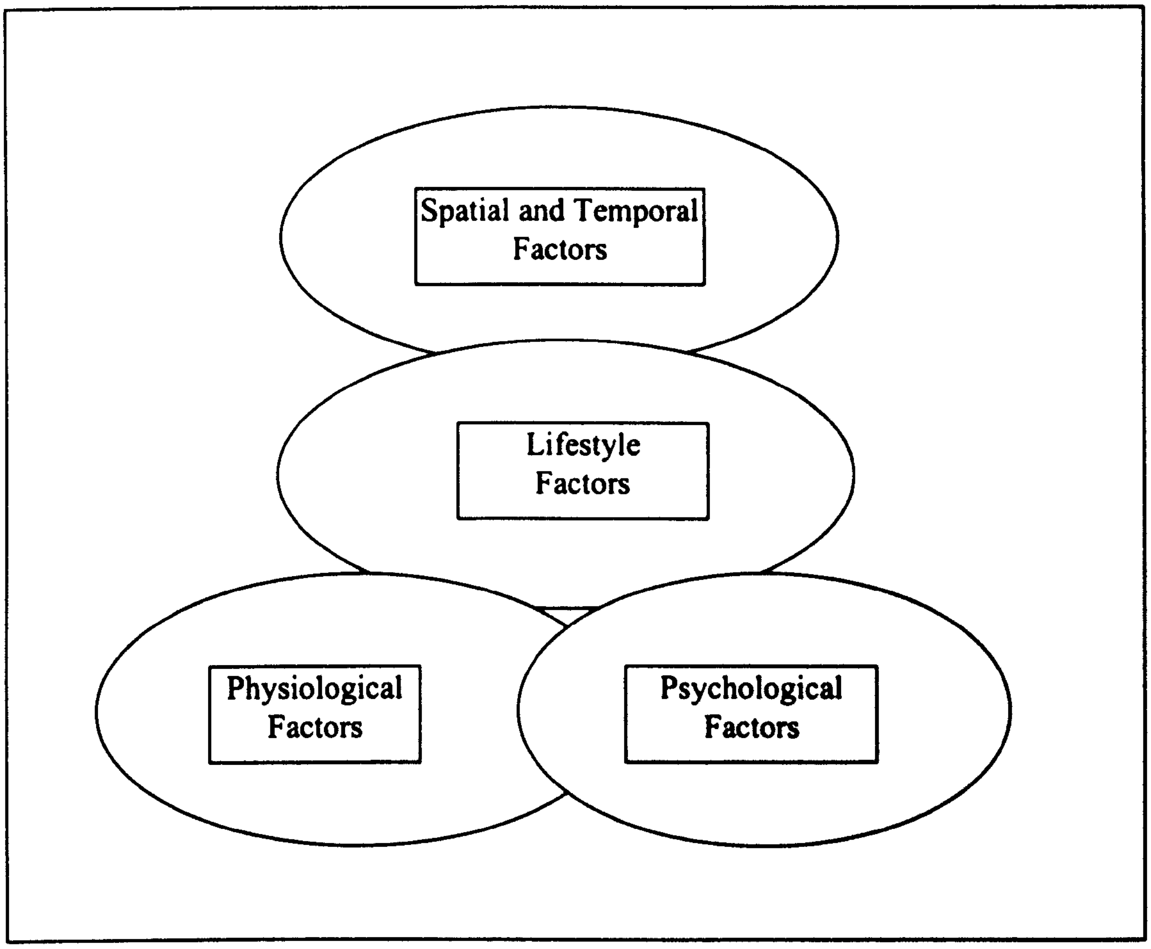


Figure 4.2: Schematic representation of the odour-monitoring tree

For example, did one monitor report an odour that they detected, which their neighbour did not because their neighbour was absent from home. By obtaining more data on monitors and more detailed reports, it was hoped to gain more information on individual variability in exposure to odour, as well as more information on the extent of odour impact. The data provided would be inspected to identify patterns in general reporting behaviour.

4.5.3 Re-design of monitor panel

The shortcomings of the initial panel were recognised when the data produced were analysed. Taking this and the model of response into account, the panel design was changed to include firstly, a new method of recording data and secondly, obtaining more information on the attributes of volunteers. This is discussed further in Chapters 5 and 6.

The panel members were asked to complete pre-printed report sheets (see Appendix A) rather than record their results in blank notebooks and were asked to sniff for odours at the same time of day, rather than at any time, so as to overcome the problem of missing and incomplete reports. They were asked to complete brief questionnaires to provide information about themselves, so that the effects of personal attributes could be identified, including smoking habits, working patterns and opinion of the Marston Vale (Appendix A). They were also asked to complete a diary for one week, recording times when they were away from home (Appendix A). It would then be possible to estimate the length of time individuals could be exposed to odour.

Monitors were asked to sniff the air outside their homes daily and report if they detected an odour or not. If they did detect an odour, they provided information on what they thought the odour source was, the characteristics of the odour, its duration and the details of the circumstances the odour was detected in.

4.5.4 Monitors reports and data handling

The monitors' reports were examined to identify patterns in reporting. This involved breaking the reports down by differing monitors attributes, such as age, gender, working pattern and length of time monitoring. The reports were broken down by area, to identify locations more or less likely to experience odours, particularly landfill odours.

As a means of assessing the accuracy of reports, monitors were asked to describe cloud and visibility at the time of their report. These descriptions were then compared with other monitors' reports to see if the descriptions were similar. It was also decided to compare the monitors' reports to wind direction and wind speed recorded at the time of their report. This was undertaken to identify if the report was likely to be an accurate reflection of an odour event taking place. It was also useful to identify monitors who appeared to be more or less accurate with their reports.

4.5.5 Monitors leaving the panel

When the monitors had left the panel, they were asked to complete post-monitoring questionnaires. These questionnaires asked them questions relating to the monitoring in order to get the monitors perspective of taking part in the project. They were also asked what they thought of their odour reports, why they had volunteered to monitor and if they had ever complained about odours. Some of these questions had to be asked after monitoring, but others, it was thought, may have influenced monitors reports. Hence the questions were asked when the monitors had left the panel.

4.6 Concluding comments

The research question asks to what extent the personal attributes of the individual, their physiology, lifestyle and location, influence their exposure to landfill odour. It also attempts to outline a framework within which a model could be developed. The three objectives arising from this question relate specifically to identification of a framework within which a model could be developed (objective 1) and the two objectives on which such activities depend. These two objectives are firstly to demonstrate the variability of response to odour found in a population due to physiological and lifestyle attributes (objective 2) and secondly, identify how spatial and temporal factors influence exposure (objective 3).

In order to answer these questions the use of an odour-monitoring panel was selected in preference to other techniques. The use of GC-MS and other laboratory-based techniques were judged inappropriate for work identifying the variability of response to odour in the field. The possibility of using dispersion modeling was examined and rejected on account of it being unable to provide information on the qualitative aspects odour impact, such as duration of exposure and intensity of odour. It was also decided that dispersion modeling might not be appropriate for use in conjunction with landfill odour emission. The landfill as an odour source, which forms the case study for this research, is perhaps is complex and contains many "unknowns" which a dispersion model could not easily deal with.

The use of a panel was selected in preference to using complaint data or social surveys, for the following reasons. Firstly, complaint data may not give a complete picture of the extent of nuisance. Also, nothing is known of the personal attributes of individuals making complaints apart from their location and the time of the complaint. Social surveys could be designed to ask for information about respondents' backgrounds, but they rely on recall and may be subject to the vagaries of press campaigns or bad publicity. The use of a panel could overcome these problems whilst providing insight into the experience of odour pollution in conjunction with the attributes of individuals. It could be designed as follows,

- To obtain background information on panel members, to identify their personal attributes
- To test the panel members olfactory ability
- To produce standard reports of odour events

By doing this, variables affecting exposure and response to odours could be identified and a framework developed. Such a framework could form the basis for a population response model. Such research could also take into account the importance of spatial and temporal factors in odour pollution events.

Chapter 5

The Pilot Study and the Case Study Context

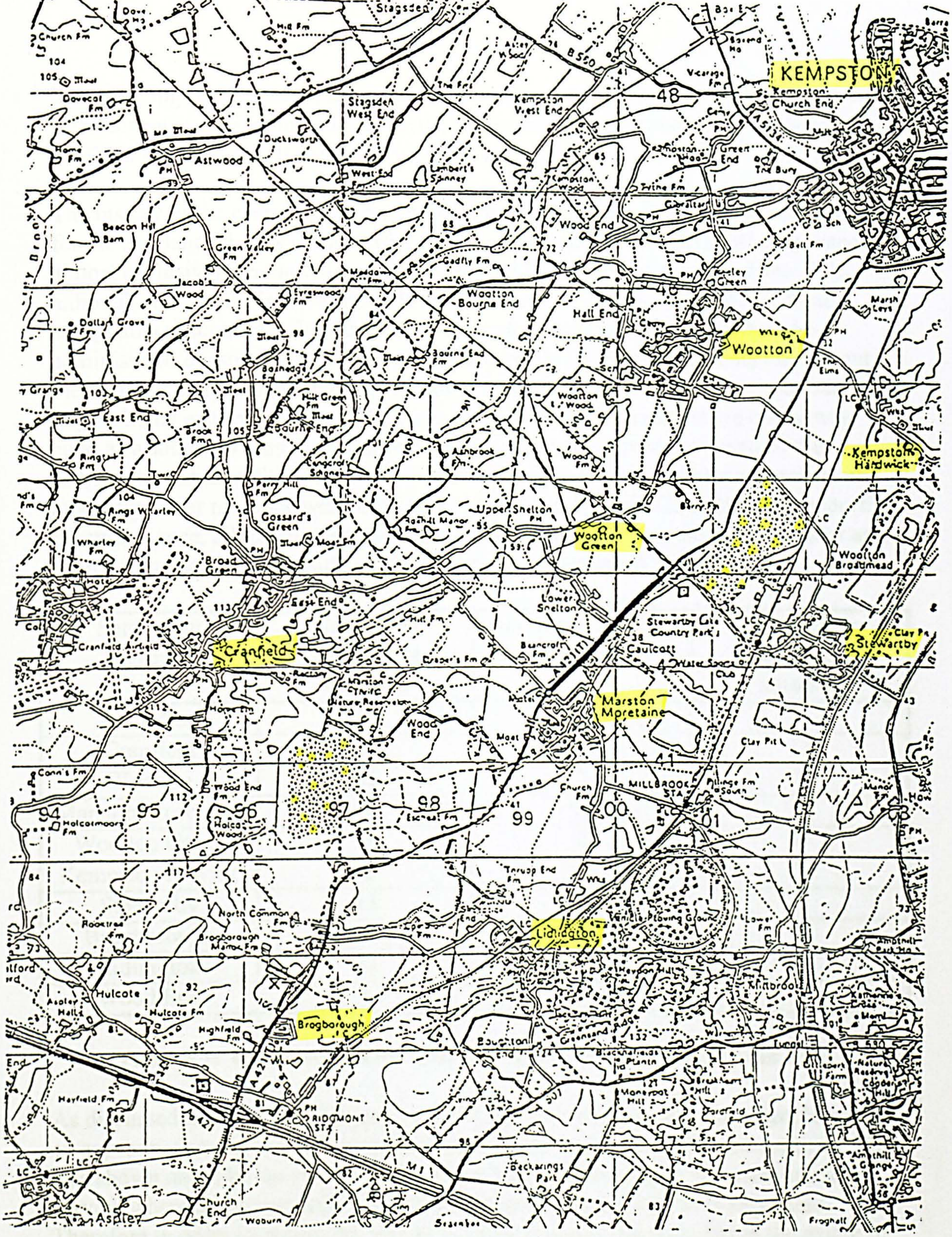
5.1 Introduction

In the previous chapters of the thesis, important background information and concepts were introduced. In Chapter 2, the variability of the ability of the individual to detect and respond to odour was discussed. It was noted that the experience of odour can vary markedly between individuals, and is not merely a physiological process, but also an emotional one. In this respect, odour is a unique atmospheric pollutant in its possible effects on individuals and communities. In Chapter 3, the methods available to researchers working on odour pollution were discussed. It was noted that the techniques divided into two major groups. These were instrument-based techniques and sensory or social methods. Such techniques can be used separately or together, although the usual scenario is for the techniques to be used individually. Finally, in Chapter 4, the research objectives and questions arising from them and the research method were discussed. It was argued that in order to identify the variability of response present in the community, the use of a population odour-monitoring panel would be appropriate.

In this chapter, the research context, landfill odour pollution in the Marston Vale area of Bedfordshire, and the project history are described. Previous research activity on this issue and how it affected the research activities for this thesis are also presented. The history of the project, discussed in Section 5.2, will be seen to have influenced much of the research activity, particularly the use of the pilot panel. This included the development of an 'odour monitoring tree', discussed in Section 5.3, which attempted to clarify the circumstances surrounding the exposure and response of the individual. It was based on the olfactory factors identified in Chapter 2, as well as reports from the pilot panel, first discussed in Section 4.5. Data from the pilot panel also influenced further activity related to the design of a new panel used for this research.

5.2 The research context: Landfill odour pollution in the Marston Vale

The Marston Vale area of Bedfordshire is located to the southwest of Bedford (Ordinance Survey Landranger map 153, grid reference easting 493000 to 504000, northing 234000 to 247000) and is shown in Figure 5.1. It has an area of approximately 110km^2 and contains a number of villages. Agriculture forms the dominant landuse throughout the Vale. There are two brickworks located at the villages of Stewartby and Kempston Hardwick. One landfill operator runs two sites at Stewartby and 2km north of Brogborough village (these have been shaded on Figure 5.1). There is another landfill located to the south of Bedford at Elstow, on the northern border of the Vale. There are two main roads within or on the margins of the Vale. These are the A421, running from Bedford to Milton Keynes and the M1



Key to Figure 5.1:

Landfill sites

Monitor locations

Figure 5.1: <u>Map of the Marston Vale in Bedfordshire</u>

located along the southern margin of the Vale. Therefore, within the Vale there are different sources of odour. The landfills, the brickworks, agricultural practices and traffic in the Vale are all potential odour sources.

The history of the case study is found in complaints made to the operator responsible for the two landfill sites at Stewartby and Brogborough. The complaints originated almost exclusively in the village of Cranfield (95%), in the southwest of the Vale, although some arose in Stewartby (5%). The operator wished to identify if these complaints accurately reflected the extent of odour impact from their sites. An administered questionnaire survey was conducted in 1993 at settlements throughout the Marston Vale (Longhurst and Cousins 1994). It revealed that, far from odour impact being centred on Cranfield, there were other settlements, where odour was cited as a source of nuisance. The results of the survey showed that most of the settlements listed in Table 5.1 reported general odour nuisance. Two settlements not reporting odour nuisance were Lidlington and Wood End. Of the settlements reporting odour nuisance, all except Kempston and Wootton Green, reported landfill odour as a source of nuisance. The results of the survey are summarised below.

Settlement surveyed	Number of households surveyed	Reference to odour nuisance	Reference to landfill odour nuisance
Kempston	40	3	0
Cranfield	73	17	12
Wootton	62	7	2
Marston Moretaine	41	21	9
Wootton Green	15	2	0
Kempston H'wick	2	2	2
Stewartby	13	5	2
Brogborough	4	1	1
Lidlington	22	0	0
Wood End	9	0	0

Table 5.1: The results of the Questionnaire survey conducted in 1993

As discussed in Section 4.2, there is some disagreement about whether complaints are an appropriate means of assessing the impact odour has on affected communities. This was shown not to be the case in the Marston Vale, as revealed by the questionnaire survey, where odour nuisance was more widespread than complaints suggested. Therefore in order to clarify the picture of odour impact, that is to assess the extent of odour impact, a pilot study using a monitor panel was instigated by staff at the International Ecotechnology Centre (see Section 4.5 and Table 4.4).

A small odour monitor panel, of 19 people, was organised, located at settlements throughout the Vale. The monitors were people who were interviewed during the questionnaire survey and had stated that they would be willing to take part in a panel. They attended meetings where the project was explained to them and they were told what was required of the odour monitor. They simply had to sniff the air on a daily basis at a time of their own choice and report if they smelled any odours and record the details. They sent their reports to the Centre on a monthly basis. Odours were divided into 4 categories. They were landfill, brickworks, agricultural and local (other) odours. They also underwent simple tests to assess their sense of smell (discussed in greater detail in Chapter 6). The tests assessed their ability to discriminate between different odours and their ability to detect different odour intensities and thresholds. The panel commenced work in 1994, prior to the beginning of this research.

During 1996, the data submitted by the monitors were examined in detail during the course of this research. The data were broken down so that reports were examined on the basis by monitor location, gender, age and employment. This method of report breakdown was selected on the basis of factors affecting olfactory ability identified in Chapter 2. Certain patterns of reporting emerged, briefly summarised below.

- The breakdown of odour reports is shown in Table 5.2. It is apparent that landfill odours were most frequently reported, followed by local and brickwork odours.

Odour type	% reports
Local odours	**27**
Landfill odours	**34**
Brickworks odours	**27**
Agricultural odours	**12**

Table 5.2: Percentages of different odours reported by pilot study panel

- Certain locations produced more reports of odour of different types than others. The breakdown of the most commonly reported odour source reported at each settlement is shown in Table 5.3.

Location	Odour type most frequently reported
Brogborough	**Local**
Cranfield	**Local**
Kempston	**Brickwork + Landfill**
Kempston Hardwick	**Brickwork**
Lidlington	**Local**
Marston Moretaine	**Brickwork**
Stewartby	**Landfill**
Wootton	**Brickwork + Landfill**
Wootton Green	**Agricultural**

Table 5.3: Most commonly reported odour at each location

- Different types of odour varied in the number of times they were reported. The times of reports peaked at certain times (8am, 3pm and 7pm). Landfill odours were most frequently reported at 8am and 7pm.

- Monitors varied on the total number of days when they submitted reports. It was not clear if this affected the numbers of reports they submitted. For example, one monitor provided reports on 59 days out of a possible 184 days (32.1%), whilst another monitor provided data on all 184 days. Some monitors reported when they were absent and unable to make reports, but others did not. The quality of reporting is discussed below.

- There were differences in report numbers based on gender and age. The results can be briefly summarised as follows. Male monitors reported landfill odours most frequently (51% of reports). Female monitors reported brickwork odours most often (38%). The age group 36 to 45 years of age reported odours most frequently and the 56+ years age group least frequently. The 18 to 25 age group reported landfill odours most frequently, the 56+ group reported brickwork odours most often. An attempt was made to identify if employment pattern affected report numbers, but unfortunately not all monitors reported if they worked full- or part-time and what their jobs were, or if they were economically inactive.

The inspection of the data from the pilot panel revealed two major areas of interest that related to the research questions discussed in Chapter 4. The first issue that came to light was that the design of the reporting method resulted in apparently missing or incomplete reports being made. Some monitors did not provide all the information required, so that reports did not have details such as the time or odour type. This made including their reports in the analysis difficult. Monitors also did not state why a report had not been made. Therefore it was not known if the report had not been made due to behavioural factors such as their forgetting to monitor, to their being ill or away from home at that time. It should be remembered that the research questions involved trying to identify the extent of odour exposure in different communities or amongst different types of individual. Therefore missing reports resulted in loss of data on exposure and detection levels experienced by communities and individuals. The identification of causes of missing reports was an important part of development of the odour-monitoring tree (see Section 5.3), which attempts to identify the circumstances behind monitoring for odours. In an attempt to overcome the problem of missing reports, report sheets with lists of questions and guidance notes for monitors were provided (see 6.4.4 and Appendix A).

The second area of interest related to the results that were obtained from the data analysis. It became apparent that there were peak times for reports, in the morning, the mid- and late afternoon. Was this pattern associated with the monitors' behaviour? (see research questions in Section 4.2). The different locations where monitors were situated produced different levels of odour report (see research questions in Section 4.2). As with the missing reports, these results helped generate more detailed questions related to how the behaviour of individuals and their location may affect exposure levels. The times when most reports were made were those when people are most likely to wake up and go out to work (8am), and when they come home again from work or from errands, for example bringing children home from school (3pm and 7pm). Therefore, did these peaks arise as a result of individuals being present to smell the odours or due, perhaps to the odour sources commencing or finishing work at those times. It was expected that more complete reports, providing information on monitors' locations, behaviour and reporting times would clarify the circumstances surrounding odour reports.

Similarly, the reports generated by monitors at different settlements showed that the villages were affected by differing odours. It would be anticipated that the settlements reporting landfill or brickwork odours would be those which were to the northeast of the relevant odour sources, as the prevailing wind blows from the southwest. However, this was not always the case. The settlements to the south and west of the vale, Cranfield, Brogborough and Lidlington reported local odours most frequently. This suggested this pattern was due to their being upwind of the landfill sites in the vale. Marston Moretaine monitors reported brickwork odour most frequently, despite being upwind of that source. Landfill odour was not so frequently reported although it is in the same direction as the brickworks. Stewartby monitors reported landfill odour most frequently. Proximity cannot explain the discrepancy of landfill odour being reported, but brickwork odour not being reported as Stewartby adjoins both types of odour source. The monitor at Kempston Hardwick reported brickwork odour most often, even though the Lfield site is to the southwest. Wootton and Kempston reported brickwork and landfill odour most frequently, even though they were not to the northeast of these sites, which would place them downwind of the sites. Wootton Green was the exception in producing agricultural odour reports most frequently. On a basic sketch map (Figure 5.2), it can be seen that the settlements between the northwest and the southeast (Wootton Green, Cranfield, Brogborough and Lidlington) did not report landfill or brickwork odours the most often. Settlements between the southeast and northwest (Marston Moretaine, Stewartby, Kempston Hardwick, Kempston and Wootton) did report these specific odours most frequently. It was decided to compare the reports from the re-designed monitoring panel with wind direction and speed to identify if there was a relationship. It was apparent that individuals at different locations in the vale had differing experiences of odour. It was notable that whilst landfill odour was frequently reported by monitors and this agreed with the complaints data, Cranfield monitors did not report landfill odour most frequently. This was despite it being the source of nearly all complaints relating to this odour. This in itself illustrated the danger of relying on complaints data as a means of odour impact assessment.

It has been highlighted in Chapter 2 that there are a number of attributes that will affect exposure and response to odours. There were differences in report patterns amongst monitors of differing ages and genders. The background information on the pilot panel monitors was limited. Their age, gender and occupations were known, but other information such as health, smoking and occupational exposure to harmful materials were not. Therefore, all these attributes may affect the ability to detect odours could not be examined. It was decided as a result of this to obtain more information from a pre-monitoring questionnaire (see 6.4.2). The differences in reporting patterns between different age groups and gender again gave rise to further questions about other factors, discussed in Chapter 2, which may also influence odour detection. The questions arising from the analysis are summarised overleaf in Table 5.4. It can be seen that these questions are directly related to the research questions raised in Section 4.2. Questions 7 and 9 relate to the first research question addressing how physiological attributes affect odour exposure. Questions 4 and 5 relate to the second research question addressing how behavioural factors influence exposure to

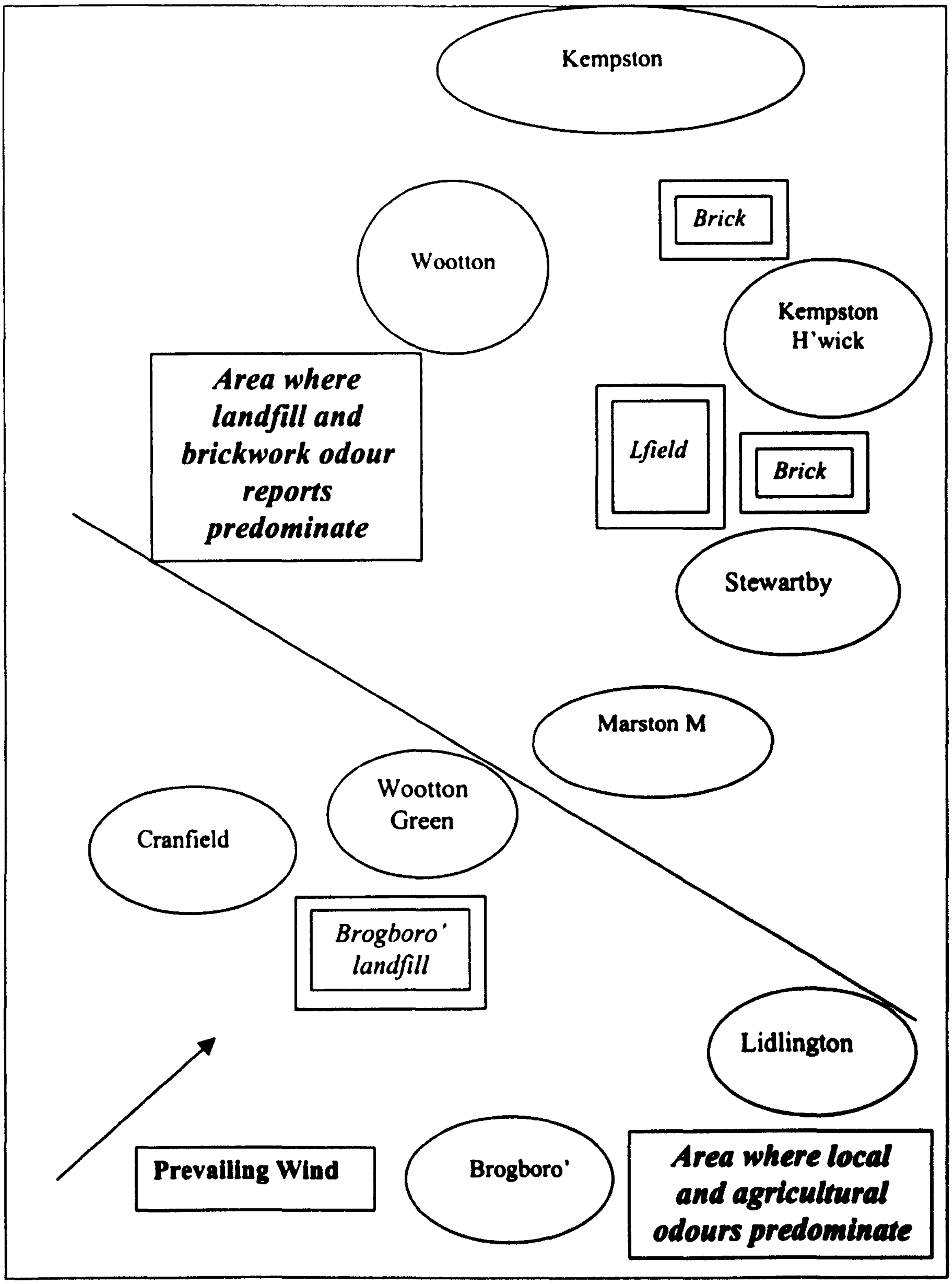


Figure 5.2: Simple sketch map showing settlement, landfill and brickwork locations.

(The line running through the map from middle left to bottom right separates the settlements reporting landfill and brickwork odour, from those that did not) odour. Questions 1 and 6 relate to the third question raised in Section 4.2, which examines the importance of location in odour reports. Some of the questions shown in Table 5.4 relate to more than one research question. Questions 2 and 11 below relate to the first and second research questions. Questions 8 and 10 relate to all the research questions.

Result from pilot study and data analysis	Question raised
Settlements affected by different odour types	**1. Does this arise due to environmental factors, such as location? (Chapters 3 and 4) (see Chapter 8)** **2. Is it a result of the type of monitor and their lifestyle found at each location? (Chapter 2) (see Chapters 7 and 8)**
Peak reporting times	**3. Does this arise due to operational factors on site? (Chapter 4)** **4. Does this arise due to monitor lifestyle? (Chapter 2) (see Chapter 7)**
Variation in number of days reports were made and the number of reports	**5. Is this due to monitor behaviour? For example work patterns, length of time spent outside (Chapter 2) (see Chapter7)**
Variation in reports made by different age groups	**6. Is this due to the locations where different monitors live? (Chapters 3 and 4) (see Chapter 8)** **7. Is it due to age alone? (Chapter 2) (see Chapter7)** **8. Is there interplay of other factors, for example age and location, lifestyle (Chapters 2 and 3) (see Chapter7)**
Variations in reports made by gender	**9. As with results from age groups, is the result seen the product of gender?(Chapter 2) (see Chapter 7)** **10. Is it the result of other factors, such as location, age? (Chapter 2) (see Chapters 7 and 8)**
Possible variation in other groups such as smokers and non-smokers	**11. Due to the different report patterns due to age and gender, was there other attributes such as health which may influence exposure levels? (Chapter 2) (see Chapter 7)**

Table 5.4: Summary of questions raised from analysis of pilot study data

It can be seen from the summary in Table 5.4, that there were many questions raised from the pilot study. It should also be noted that the questions fall into categories relating to the components of the issue identified in Section 4.2 and Figure 4.1. These components were identified as physical, physiological, psychological and lifestyle factors and permeate all the research questions raised. For example, the observation that certain settlements appeared to be affected by a particular odour type posed the following questions. Firstly, did this pattern arise due to the location of the monitor relative to the site? (a physical factor) or, secondly, was this pattern due to a particular type of monitor being present at a particular settlement? (a physiological factor). Examination of these and the other questions showed that they all fell into one of the issue components. Therefore a more detailed picture of the circumstances that leads to an individual being exposed to an odour, their detecting it and responding to it began to be assembled. This was discussed in Chapter 4, where the factors were roughly grouped together to form a tree of relationships (see Figure 4.2). This was expanded when the research questions were identified to develop a more detailed odour-monitoring tree, showing possible explanations of how an individual may or may not detect an odour. The details of the construction of the tree are discussed in Section 5.3.

The questions identified in Table 5.4 and the circumstances surrounding an individual detecting an odour identified in the odour monitoring tree led to the development of the research question and associated objectives and the design of the research activity. It became apparent from the pilot study analysis that there was variability in the odour reporting patterns, which could have been based on the attributes of individual monitors. It is proposed to identify if this is the case. The research activity, the design and operation of an odour-monitoring panel, led to the production of results that are presented in Chapters 7 and 8, on which a framework for a population response model is based. Chapter 7 examines the variability in reporting patterns produced by individual monitors. It then goes on to present the results of groups of monitors with similar attributes, age, state of health and so on (research objectives 1 and 2). These attributes were selected on the basis of other research reviewed in Chapter 2. These groupings relate directly to the development of the framework, which is presented in Chapter 10 (research objective1). Chapter 8 examines the same reporting patterns on the basis of spatiality and temporality (research objectives 1 and 3). The chapters where the results of the research activity directed at each question in Table 5.4 are shown in the right hand column.

5.3 The Odour Perception Tree and the Research Design

When the analysis of results from the pilot study was completed, the questions summarised in Table 5.4 that relate to the research objectives, and hence the key components, were raised. The odour perception tree (Figure 5.3) was designed on the questions that arose from the pilot study. The tree was based around these questions and was constructed as an attempt to understand why a monitor may or may not report an odour. The tree was developed on the basis of a simple probability tree, following a pathway of "yes" or "no" choices. For example, the first choice, "Is an odour present?" permits a choice of "odour reported" or "odour not reported". It is possible to move down the tree following pathways to identify the factor or attribute behind a

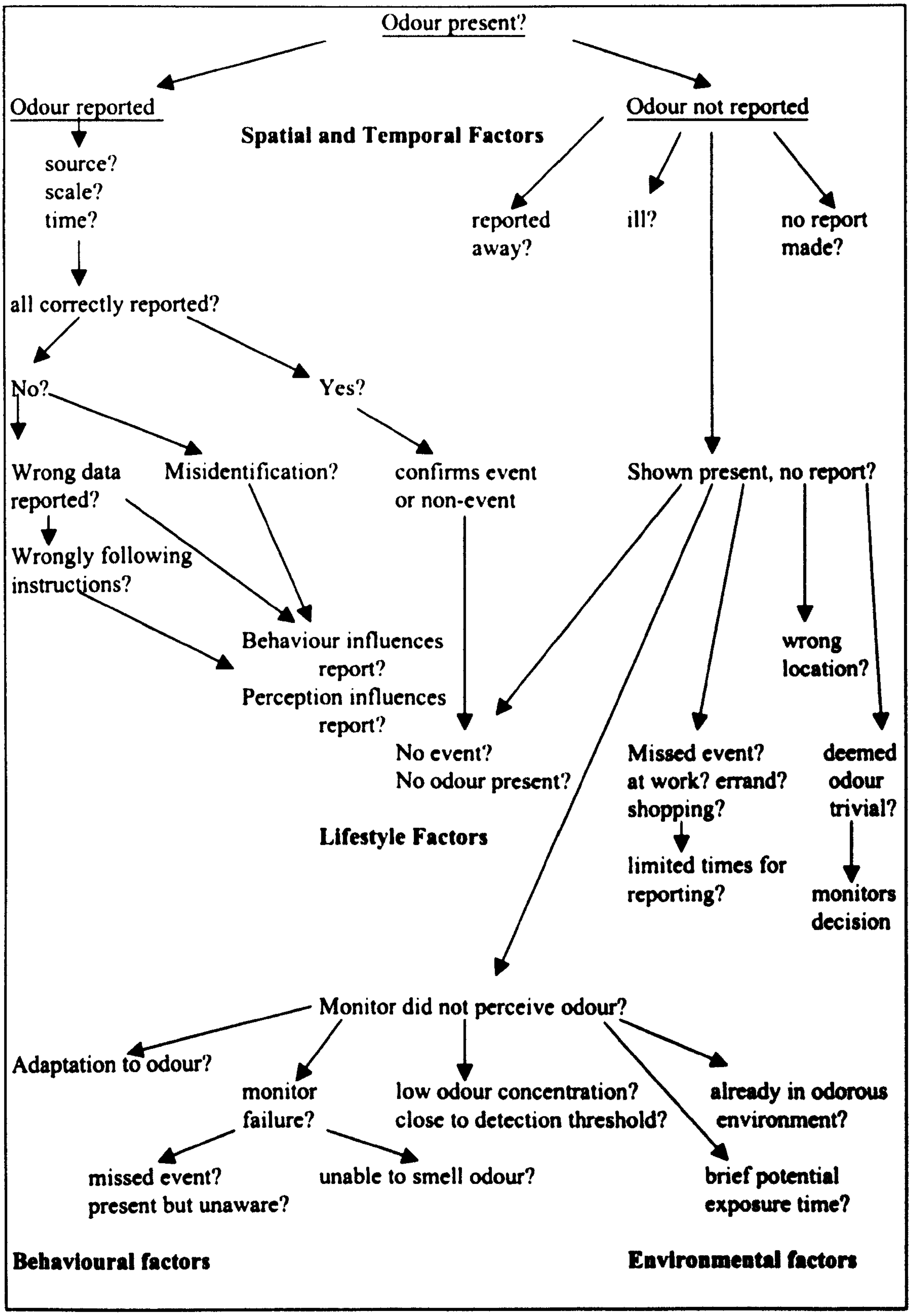


Figure 5.3: The Odour Perception Tree

report being made or not. Initial designs of a diagram representing odour detection and response were based on a flow diagram. However, it could not represent the variety of factors and attributes involved in odour response. The tree, an expanded flow diagram, was adopted as it was a simple structure that lent itself to representing the complexity of factors, attributes and events surrounding an odour incident. The attributes are grouped roughly into related areas, namely positive reports and reasons for negative reports (grouped into spatial and temporal factors, lifestyle, psychological and physiological attributes).

The tree was designed from the perspective of a member of a monitor panel and follows a range of reasons either for reporting or not reporting an odour. The tree is split into two branches, one where odour is detected and reported and one where it is not. The reasons behind a monitor sensing or not sensing an odour are based on the literature review and relate to the research question and objectives outlined in Section 5.2. In order for an individual to detect an odour, there should be some form of odour present and the individual has the ability to sense it. The basis of a tree is a description of an odour event, a situation where odour is present in the environment and there are individuals who may perceive it. It served as a means of clarifying the attributes that affect the exposure to odours and the ability to detect them. It therefore, as referred to above, helped in the design of the panel, in the data analysis in Chapters 7 and 8 and the framework developed in Chapter 10.

5.3.1 The 'odour reported branch' of the odour perception tree

Travelling down the odour reported branch, the first stage is that of 'odour reported'. This stage assumes that the monitor has detected and reported an odour. This requires all the components shown in Figure 4.1 are present. Namely, there is an active odour source and the individual is located at a point where the odour plume has travelled. They will have the physiological attributes to sense the odour and therefore can respond to it. In the case of monitoring, this response results in making a report of odour. The monitor will use their experience of their surroundings and of odours to reach this decision.

The tree was designed to illustrate what circumstances and qualities occur which lead to an individual, in this case a panel member, detecting the presence of an odour or not. On the basis of the data analysis and development of the tree, the next stages of the research activity were developed. It was decided to re-design the pilot study panel, to change how data were recorded and obtain additional information on the monitors. As briefly mentioned in 4.5.1, very little information was known about the monitors. Their gender, ages, occupations and their addresses were known. Other information, such as smoking habits, health and their employment pattern (part-time, full-time or economically inactive) were unknown. These details related directly to the components above and in Figure 4.1. So, for example, the location of the home of the monitor was a spatial factor; the health of the monitor related to physiology. Inspection of the data from the pilot study indicated that at least some of these unknown details may have influenced the reporting patterns seen. For example, did one monitor report an odour that they detected, which their neighbour did not because their neighbour was absent from home?

The monitor is asked to report certain features of the odour (see Chapter 6). These include the source of the odour, if they think they can identify it, the date and time and properties of the odour, such as its intensity or hedonic properties. Again, this requires the monitor to make judgements about what they have perceived. If the monitor has successfully identified the source and records the details in the form specified, then this confirms that there has been an odour event. The monitor has experienced and reported an odour incident. These reports formed the basis of the development of the framework in Chapter 10. The reports were also assessed for possible inconsistencies in Chapter 9.

The questions summarised in Table 5.4 can be addressed by positive reports of odour. Numbers of positive reports are useful for examining which settlements are most frequently affected by odour or most affected by odours of a particular type (research objective 3, question 1 in Table 5.4). The pilot study certainly suggested that different settlements vary in the number of times and types of odour they experience. The reports would also confirm the times of day when odours are most likely to be detected. The pilot study did suggest that odour was most likely to be reported at particular times. This information relates to the third research objective raised in Section 4.2. Spatial and temporal influences on reporting patterns are examined in Chapter 8. However, there may be other factors affecting reports, such as the type of monitors present at each location. For example, the pilot study suggested that male monitors were most likely to report landfill odour. This prompts the question what causes the pattern of certain settlements producing high numbers of landfill odour reports? Is it location close to a landfill, male monitors or both factors? More needs to be understood of the pattern of reporting amongst the different groups of monitors that make up the panel. Hence the other questions shown in Table 5.4. When this is done, then research objectives 2 and 3 can be answered. The influences of personal attributes on reporting patterns are highlighted in Chapter 7. However, care should be exercised in interpreting odour reports, as they may not always be reliable.

The monitor may record incomplete or inaccurate data. This may arise from their failing to follow instructions they were given or perhaps being rushed or distracted when carrying out monitoring. They may, no matter how careful or conscientious they are, incorrectly identify the odour source or properties of the odour. This can arise for a variety of reasons. Firstly, due to their being unable to make a correct assessment of the odour, that is their sense of smell may be physically affected or their judgement or perception may influence the report. For example, if they associate an odour from a particular source with a specific wind direction, they will record the odour as arising from that source even if the odour has different properties (see Section 2.3 and the discussion of the appreciative system of the individual). Alternatively, their behaviour can influence their report by their not following the instructions correctly. Again, as with occasions where odours are reported correctly, the monitor will be using their experience of odours and their locale to make their report. In this case, their report suggests an odour may have a particular source or properties, when this may not be the case.

5.3.2 The "odour not reported" branch of the perception tree

As with the positive odour reports, the four major components and overall research questions apply to non-reports. There are many situations that may lead to an odour not being reported. The variation in the number of reports between monitors

(Question 5) may arise from monitor behaviour. The monitor may be ill and cannot monitor or detect an odour or they are reported as being away from the area, for example on holiday. In both these cases, there may be odour present, but it is not reported. The missing report does not arise due to the absence of odour, but from the behaviour of the monitor. If they recorded themselves as present and they made no report, there are more possible reasons for their not making a report.

- There may not be an odour in the area to report at the monitor's location. This may arise due to physical factors, such as the odour source not releasing odour or the odour plume being transported away from the monitor's location (Question 6).
- The monitor may have missed the odour event, as it may have occurred at a time when they were away from home, for example at work. It is possible the monitor, due to lifestyle factors, may have a limited potential odour exposure time. This would affect their reporting times (Questions 3 and 4), and the number of days they can report and the number of reports they make (Question 5).
- The monitor did perceive an odour but deemed it trivial and decided not to report it. This is one example of how the attitude and judgement, which is part of the appreciative system of the individual may influence their experience of odour. Question 11, which asks if there are any monitor attributes that influence reporting patterns, relates to this situation. There may be variation between monitors' reporting patterns due to their opinion of the odour source, or the length of time they have lived in the area and hence their experience of the odour. There may also be differences in reporting patterns between long-term monitors and new monitors. The more experienced monitors may be more likely to use their judgement or is less motivated to report all odours.
- There may have been odour being released into the environment that was present at a monitor's home location, but the monitor was not present. It should be stressed that this is a different situation to the one referred to above where a monitor has reported himself or herself as absent. In this situation, the monitor has perhaps been absent from the area for a brief period, for example less than 30 minutes, and has missed the odour, which may have been present at a detectable concentration for a few minutes. This again relates to the behaviour of the monitor and to Question 5.

Moving further down the branch of the tree, the monitor may not have perceived the presence of an odour. This again may arise for a variety of reasons, which fall into two broad categories. These are physiological factors, and environmental factors. The physiological factors include the following.

- The monitor was present but did not perceive the odour due to their being unable to detect the odour. A possible cause could be the monitor being indoors or preoccupied by some other activity. Again this relates to the monitor's lifestyle and movements (Question 5).
- They may not be able to smell that particular odour because they are physiologically unable to do so. This may be the case due to the factors described in Chapter 2. Therefore in this instance, this relates to Questions 7, 8, 9, 10 and 11.

- They may have become adapted to the odour either on that particular exposure or they may not notice the odour at any time as they have adapted to it or become 'used to it'. This relates to question 5, relating to monitor behaviour.

Environmental factors include the following:

- The odour may be present at a very low concentration close to the detection threshold. This may mean the odour could be missed, particularly if any other factors, such as the monitor being unable to smell due to illness or being indoors, were also operating at the time. This is perhaps one situation that the research as it is designed, could not identify. However, if the odour-causing chemical is present at such a low concentration as to be undetectable, then it will not generate nuisance and a response. This relates to the environment, therefore indirectly to Questions 1 and 3.
- The odour may have been present for a very brief potential exposure time. Again, this may result in the odour being missed by monitors. It is, as has become apparent, a case of an individual being in the right place at the right time, that is monitor behaviour (Question 5).
- The odour may be missed by a monitor if they are already in an odorous environment. This may include places where odours such as tobacco or chemicals such as paints and solvents are present. This relates to their exposure to materials that will damage the olfactory apparatus and therefore relates to Question 11.

5.3.3 Conclusion to Section 5.3

The odour perception tree illustrated the complexity of the circumstances leading to the detection of odour. How it was the product of the right environmental conditions and the right individual having to be in the right place at the right time! It was therefore of great importance in identifying the key components driving odour pollution events and in generating the research questions. It was also influential in the design of the research activities. When the tree was examined in tandem with the results from the pilot panel, it became apparent, firstly, what type of data were required to understand the issue of odour exposure and detection and, secondly, how that data were to be obtained. For example, identifying where individuals were when they detected odour and what they were doing would help understand the importance of behavioural aspects of exposure and detection. Additionally, providing report forms with questions arranged as a list for monitors to use would overcome the problems of incomplete reports and therefore missing data.

5.4 Research activities

The research activities can be divided into the activities undertaken prior to the development of the odour-monitoring tree and those carried out afterwards. The initial activities included the analysis of the data from the pilot study panel discussed in Section 5.2. The subsequent activities included those discussed in Section 4.5 of the previous chapter. However they are summarised in greater detail in this section. The research activities are summarised in Figure 5.4.

- It can be seen that there was a clear sequence of events commencing with the analysis of data from the pilot monitoring panel set up in 1994, discussed in Chapter 4. This data gave rise to the development of the odour perception tree, which clarified the circumstances in which odours would or would not be perceived. Both the data analysis and the tree led to the research questions,

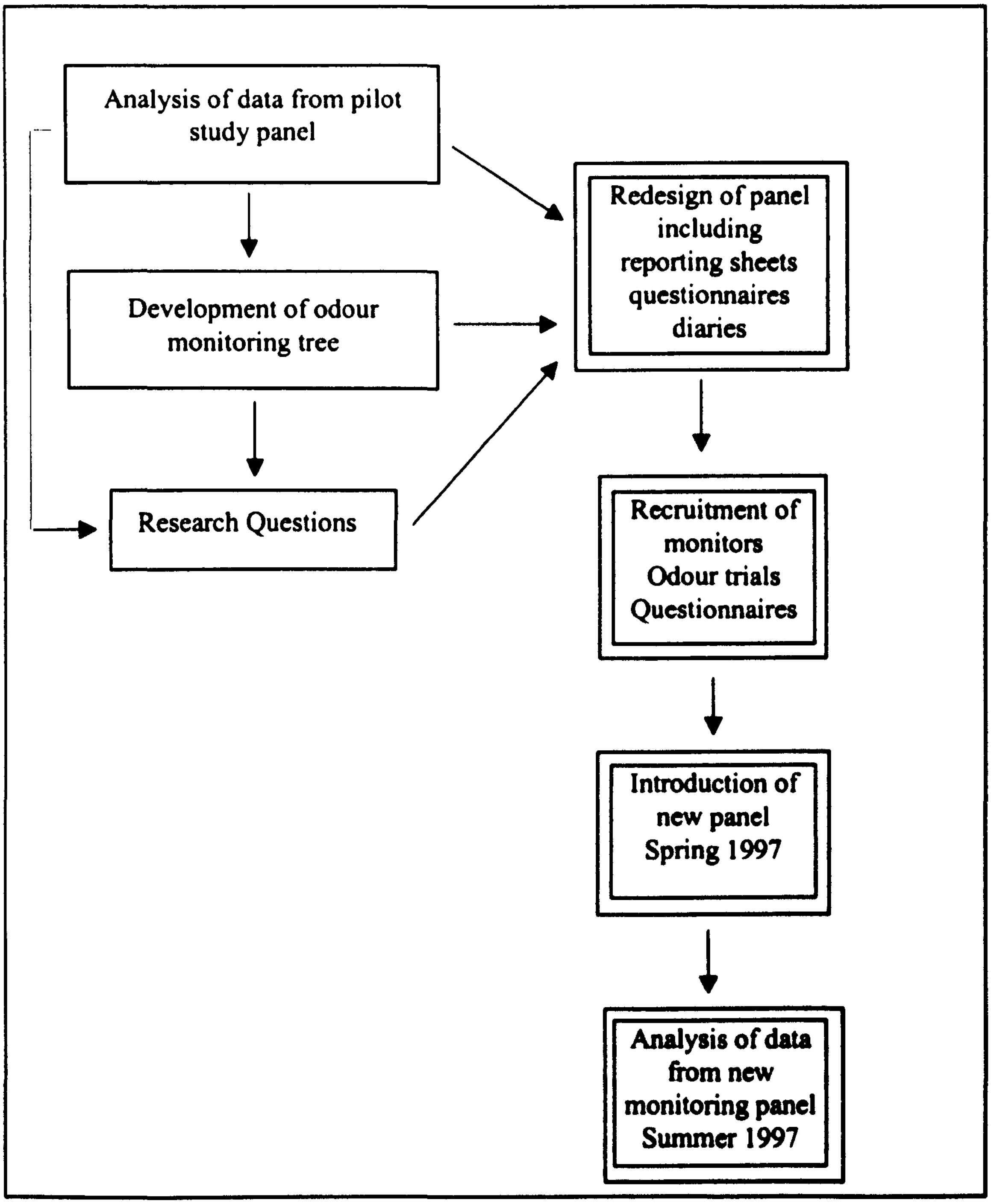


Figure 5.4: Summary of research activities

that in turn drove the changes to the design and method of the monitoring panel. Recruitment of new monitors and odour trials took place prior to the new panel being introduced in Spring 1997. The new panel generated data for analysis after being in place for three months. The re-design of the monitoring panel and subsequent activities are recounted below.

5.4.1 Re-designing the monitoring panel

The data analysis and inspection of the reporting quality led to not only the development of the monitoring tree, but also how the panel could be redesigned to provide more detailed information about the monitors. The re-design of the panel was briefly described in Section 4.5. However, in this section, the activities, prior to and during monitoring will be described in greater detail.

<u>Prior to monitoring</u>

The first activity associated with the redesign of the panel was the recruitment of new monitors. The panel from the pilot study had shrunk from 19 monitors to 12. This number was insufficient for monitoring over the large area of the Marston Vale. Therefore it was decided to recruit new members via a leaflet campaign. Leaflets were posted to selected addresses at the villages in the Vale shown in Figure 5.1 and discussed in Section 5.2. The details of recruitment are discussed in Chapter 6.

- The volunteers who came forward were invited to meetings at Cranfield University, where they were informed about the project, to complete the odour perception trials and to complete a pre-monitoring questionnaire on their backgrounds. A copy of the questionnaire is shown in Appendix A. At the same time, the long-term monitors were also invited to attend the meetings, to be informed about the changes to monitoring procedure, to re-take the odour trials and to complete the questionnaire.
- The odour trials, which are discussed in greater detail in Chapter 6, were undertaken for several reasons. Firstly, to identify individuals who had problems with their olfactory ability. Part of the study involved examining the community response to landfill odour and it would be of little use to have individuals in the panel who were anosmic to this odour type. Secondly, they were carried out to obtain insight into the qualities and variability of the sense of smell of the monitors. The trials provided benchmark information for the research questions. As has been stated earlier, surveys and complaints data do not take into account the variability of response to odour amongst the sample population or complainants.
- Similarly, the pre-monitoring questionnaire (see Chapter 6 discussion and Appendix A) completed by volunteers at the meetings was designed to provide background information on personal factors that could affect an individual's olfactory ability. These factors were identified in Section 2.2. This information directly related to the research question on how personal attributes could affect the ability to detect odour and to Questions 2, 7, 8, 9, 10 and 11 in Table 5.4. The volunteers were also asked to provide information on their occupation and how long they had lived in the Marston Vale and what they liked and disliked about the area. This information was sought to attempt to identify factors affecting their opinion of the Marston Vale and the landfill site in particular, and hence try to gain insight into the volunteers' appreciative systems. This information related to the second research question that asked how the behaviour and attitude of the individual would influence their perception of landfill odour. It, therefore, also related to Questions 2, 3, 4, 5, 8, 10 and 11 in Table 5.4.

At the commencement of and during monitoring

- For the first week of monitoring, the panel members were asked to complete a time diary (see Appendix A) that involved their recording when they were at home and therefore could be exposed to odour. By doing this it was possible to assess the monitors potential exposure time and identify patterns when monitors were most likely to report odours. For example, would they be more likely to report odours when going out or returning home, or when they had been home for some time? Again, this would provide information on the research questions related to behaviour and how it affects exposure levels.
- The monitors were supplied with pre-printed reporting sheets, a copy of which is enclosed in Appendix A. The data required from the monitors were presented as a list of questions, which it was hoped would overcome the problem of missing information. Extra questions were added to the list, such as the duration and intensity of the odour, where the monitor was when they detected the odour and what they were doing. It was hoped that more information would come to hand on the nature of odour exposure, so that not only the time and type of odour would be known, but also how long the odour was detectable and its intensity and pleasantness. It was also hoped to obtain information on the circumstances surrounding an individual detecting an odour. For example, was the individual indoors or outdoors? What were they doing at the time? This again would provide information on how the behaviour of individuals affects their exposure to odour (second research question). They were also asked to state when they were unable to monitor. This would clarify the potential exposure time of the monitor and overcome the problem of the missing days seen in the pilot study data. The volunteers were also supplied with guidance notes on how to monitor, giving details on how to complete their reports forms. It was hoped by doing this that mistakes in reporting would be avoided.

5.4.2 Analysis of reporting data

The analysis of the data took a similar form to the pilot study. The reports from each location were examined for the numbers of reports and the types of odours. This was done to identify if particular settlements appeared to experience certain odours more frequently than others (third research objective). The results of this analysis are presented in Chapter 8. The reports were also examined on the basis of monitor type. This included examining reports by groups based on physiological factors, such as age, gender and health, and groups based on behaviour, such as occupation and smoking. This would then provide information relevant to the research questions on how physiological and lifestyle factors affect reporting levels. Where appropriate, statistical tests were undertaken to assess the significance of each result. These results are presented in Chapter 7. An additional step involved comparing positive reports of landfill odour to wind speed and direction. This was undertaken in an attempt to assess the accuracy of reports. This and other means of assessing the validity of the monitors' reports are examined in Chapter 9.

5.4.3 Post-monitoring questionnaire

When monitors withdrew from the panel, they were asked to complete post-monitoring questionnaires. A copy of this is included in Appendix A. The questionnaire consisted of two types of question. Firstly, it asked questions that were deemed to be too sensitive to ask prior to monitoring. This included asking volunteers if they had ever complained about nuisance or taken avoiding action to avoid exposure to odours. It was felt inappropriate to ask these questions before they had completed monitoring as their reports may have been influenced in some way. The second question type related to taking part in monitoring and how they perceived odour after taking part in the study. These questions could not have been answered before monitoring. The information from this questionnaire, it was hoped would identify how easy or difficult the individual had found monitoring and whether their reports had confirmed the levels of odour they thought they were exposed to. They were also asked to give any other comments about the project or about living in the Marston Vale. It was hoped that, firstly, the information provided would help with further changes to monitoring procedure. Secondly, it could provide background information to the opinions of monitors to their local environment and to the landfill sites in particular. It was also hoped to identify what the motivation was for volunteering to work for the project and identify if monitors had become more aware of odours. The results from this assessment are presented in Chapter 9.

5.5 Concluding comments

In this chapter, the research context, landfill odour in the Marston Vale, and the history of the project were introduced. A pilot study, involving the use a social survey and a pilot odour-monitoring panel, were recounted. The details of how the analysis of the data from pilot study led to the development of the research question and objectives and research activity were examined. It became apparent from the inspection of the data that the pilot study monitors produced varying levels of reports that may have been the product of their location and/or personal attributes. The influence of personal attributes such as age or health had been identified from the literature review in Chapter 2. A number of questions were generated from the pilot study that are summarised in Table 5.4. These questions were related to information contained within Chapters 2 and 3, as well as to the analysis of data from activity undertaken for this research that is presented in Chapters 7 and 8. An aid to understanding the circumstances surrounding a monitor reporting odours or not was developed. This was the odour monitoring tree.

These insights led to the design of the research activity. This involved redesigning the monitoring panel, expanding it and changing the means of recording reports. This was to ensure that a larger number of people could be involved in the study and would produce reports of a more consistent quality. It also involved the inclusion of questionnaires to be given to monitors at the beginning and end of the monitoring period. The personal attributes of the pilot study monitors had suggested that such attributes may have influenced reporting patterns. A pre-monitoring questionnaire was designed to gain some idea of the monitors' backgrounds, such as their ages, health, employment pattern and opinions of the Marston Vale. The post-monitoring questionnaire was introduced to gain more insight into the monitors' motivation for volunteering and their opinions of monitoring. The details of these activities are presented in Chapter 6.

Chapter 6

The design and operation of Community Odour Monitoring

6.1 Introduction

This chapter discusses the design and method of the monitoring panel, including monitor selection and testing, how additional information on monitors was obtained and how monitoring was carried out. The reasoning behind each activity is given, but it should be remembered that a major purpose of the panel was to demonstrate how the experience of odour could vary between people living in the same area. Thereby providing an answer to the research question given in Sections 1.6 and 4.2. Section 6.2 discusses the background to creating the pilot odour-monitoring panel in the Marston Vale. It reiterates pertinent details discussed elsewhere in the thesis and includes details of the pilot study, including the population survey and the decision to use a monitor panel. It will be recalled the pilot study panel reults indicated monitors' reporting levels varied due to location and personal attributes. As the research question asks whether exposure to odours can be influenced by attributes such as age or health, it was decided to use a redesigned monitoring panel, rather than other methods such as the use of dispersion models. The output had to relate to the levels of odours detected by the local population and other technical and sensory methods would not provide the information required namely individuals in the environment producing reports of odours they detected. It was to be these odour reports that would be used to develop the population response framework (Chapter 10). Some problems with using a panel had been identified, namely missing or incomplete reports. It was hoped that a redesigned panel would overcome these problems.

Section 6.3 discusses the selection and procedure of the pilot monitoring panel. Section 6.4 discusses the re-design of the monitor panel, recruitment of new monitors and the changes to monitoring procedure. These changes were based on the analysis of data from the pilot panel, the questions the panel raised and the odour monitoring tree clarifying the circumstances surrounding odour detection. The difficulties surrounding this process are also related. Section 6.5 highlights the number of monitors and their backgrounds used in this research. It was decided to analyse the monitors' reports on the basis of individuals and groups. The groups would be based on common attributes, such as age and gender, which were believed to influence the ability to detect odours. Section 6.6 presents the results of the olfactometry trials. The results from the panel are summarised in Chapters 7 and 8.

6.2 Creating an odour monitoring panel

This section summarises the history of the project discussed in Section 5.2, as well as reiterating pertinent points from previous chapters. As discussed in Chapters 3 and 4, reliance on complaints to the operator of an odour source, in this case landfill odour, is not always a useful way to identify how severe the impact is. Complaints compiled by Shanks and McEwan, the operator of Brogborough and Lfield landfill sites, originated almost completely at Cranfield, a village 2km west of the Brogborough site, with a few complaints made at Stewartby. Further information was sought to identify any other settlements that were affected by odour from the landfill sites. An administered questionnaire survey was conducted in 1993 at settlements in the Vale (Longhurst and Cousins 1994). These included Brogborough, Cranfield, Kempston, Kempston Hardwick, Lidlington, Marston Moretaine, Stewartby, Wootton and Wootton Green (see Figure 5.1). It was designed

- firstly, to identify the extent of perceived environmental nuisance.
- secondly, to identify perception of and concern about air quality.
- thirdly, to identify the extent of odour nuisance.

The survey results indicated that odour nuisance was far more widespread across the Marston Vale than what the distribution of complaints would suggest, and was not concentrated on Cranfield. The reasons why complaints data may not be reliable are discussed in Section 4.2, but they are summarised here. Firstly, individuals may be reluctant to complain and possibly do not know to whom they should complain. Secondly, the level of complaints may be affected by publicity relating to an odour source. Another drawback of relying on complaints data is that it may not supply information on the odour event, other than there is an odour at a particular time and place.

An odour monitor panel could provide long-term, detailed information on the presence of odour, which unlike survey data is not reliant on recall, or like complaint data not provided in annoyance. The monitors could be pre-selected to ensure their sense of smell was not impaired in some way. It was decided to introduce a monitor panel in the Marston Vale to provide more information on odour pollution events. This would include the frequency, duration, location and types of odour experienced by monitors in the Vale.

At the time when the questionnaire interview was conducted, respondents were asked if they were willing to volunteer as odour monitoring panelists. The respondents who did volunteer attended meetings at the International Ecotechnology Research Centre (IERC). These meetings told them what a monitor would be expected to do and to have their olfactory function tested (see Section 6.3). A monitoring panel consisting of 20 people was then put in place and started monitoring during 1994.

6.3 Monitoring selection and procedure 1994 to Spring 1997

Respondents in the questionnaire survey were asked if they would like volunteer as odour monitor panelists. Those who expressed an interest attended meetings at IERC. They took part in a simple odour perception test and were told what monitors were required to do. Section 6.3.1 discusses the odour perception trials, what they were and how they were administered. Section 6.3.2 discusses what monitors were asked to do as panelists.

6.3.1 The odour perception tests

It was decided to ask the volunteers to take part in simple tests on their olfactory ability. There were three different odour perception tests, based on detection and description of differing dilutions of odourant chemicals. These were tests for odour discrimination, ability to assess odour thresholds and assess odour intensity. The tests were carried out to screen out volunteers who had problems such as anosmia or elevated detection thresholds (see Chapter 2).

The tests also illustrated the variability of the sense of smell between monitors included in the panel. As discussed in Chapter 5, monitors' reports from the pilot panel suggested that the personal attributes of monitors may have had a bearing on the reports they made or did not make. This led in turn to the research questions raised in Chapter 4. After the second set of odour trials for the panel used in this research, the results produced by different sets of monitors, such as males and females, smokers and non-smokers, were analysed to identify if these attributes did affect their sense of smell. By doing this, the research questions related to how personal and behavioural attributes of monitors could affect their ability to detect odours could be addressed.

Artificial odours for all tests were produced in the laboratory and were presented to volunteers in labeled 250ml flasks, sealed with natural corks. The chemicals used, which were recognised as safe (GRAS - Longhurst and Cousins 1994) odourants, were diluted with solvents. COSHH assessments were made on all the odourants used. The odourant chemicals used were all diluted by 1% volume in pure ethyl alcohol, which were retained as stock solution. Subsequent dilutions were made using distilled water to produce a buffer solution of the required concentration to be presented to the volunteers. All the solutions were colourless.

In the odour discrimination test, five artificial odours were presented to the volunteers to test their ability to detect and describe different odours. The odour types used were 'floral', 'fruity', 'mint', 'fishy' and 'putrid'. Table 6.1 lists the odour type, the chemical used and its dilution.

Odour type	Chemical used	Dilution
Floral	**Phenyl Ethyl Alcohol**	**1×10^{-4} %**
Fruity	**Ethyl butyrate**	**5×10^{-5} %**
Mint	**Menthone**	**2×10^{-6} %**
Fishy	**Trimethylamine**	**4.5×10^{-6} %**
Putrid	**Dodecyl Mercaptan**	**5×10^{-7} %**

Table 6.1: Odour type, chemical used and dilution used in odour discrimination test

During the trials the volunteers were asked to sniff the flasks in a specific, standard fashion. They were asked to swirl the flask gently, take a moderate sniff of the contents, then turn away and breathe normally. They could repeat this activity if they wished. They were given a list of the five different odour types and asked to select a description of the odour sniffed from the list.

The odour threshold test was undertaken to identify volunteers with specific anosmia. A series of flasks containing decreasing concentrations of dodecyl mercaptan were presented to the volunteers. The concentration of the dodecyl mercaptan decreased successively by 50%. The concentrations used are shown in Table 6.2.

Threshold test		Intensity test	
Flask	**Concentration**	**Flask**	**Concentration**
1	6.25×10^{-8} %	1	5×10^{-7} %
2	3.13×10^{-8} %	2	1.25×10^{-7} %
3	1.5×10^{-8} %	3	6.25×10^{-8} %
4	7×10^{-9} %	4	3.13×10^{-8} %
5	2×10^{-9} %	5	1.5×10^{-8} %

Table 6.2: Concentration of dodecyl mercaptan used in odour threshold and intensity tests

The arrangement of the test took the form of a triangle test adapted from olfactometry tests developed by Dravineks and Prokop (1975). This is a commonly used test used to encourage subjects to discriminate between odorous and non-odorous samples. There were five groups of three flasks, one of which contained the odour-causing compound, the other two blank flasks contained distilled water. The volunteers were asked to state which flask of the three contained the odourant in each of the five groups. Dodecyl mercaptan was used as the odourant compound as mercaptans can be found as a constituent of landfill odour as well as brickwork and agricultural odours (Verschueren 1977, Young and Parker 1983, Rettenberger and Stegmann 1991). For example, Young and Parker (1983, 1984) reported detecting mercaptans in emissions from eight landfill sites. Three of these sites accepted domestic waste and five that accepted both domestic and industrial wastes. They discuss how sulphur bearing species can be mistaken for the "bad egg" odour of hydrogen sulphide and how they require substantial dilution in order to cease to be detected. These odours would be common in the Marston Vale, where all three sources were present. The volunteers sniffed these flasks in the same fashion as in the odour discrimination test.

The final test was the odour intensity test. This was carried out to assess the volunteers' ability to identify smell strength. Five flasks containing decreasing concentrations of dodecyl mercaptan were presented to the volunteers for testing. The concentrations used are shown in Table 6.2. They were asked to place the flasks in order of strength and then score the different strengths on a scale of 1 for the weakest odour to 100 for the strongest. Again the volunteers sniffed the flasks in the same fashion described above.

6.3.2 Monitoring Procedure for the pilot panel

At the meetings, volunteers were also told what they were expected to do as monitors. They were asked to monitor on a daily basis, by sniffing the air once a day, and report if they could detect an odour or not. If they smelled an odour at any other time, they were asked to report details of that odour also. They were asked to provide the following information,

- The date.
- The time the monitor smelled the air for odours (or the time the odour was detected if a second odour was detected).
- Details of the odour - the source (if the monitor could identify it)
  how certain the monitor was of their choice of source
  the intensity of the odour marked on a scale of 1 for a very weak odour to 7 for a very strong odour
  the pleasantness of the odour marked on a scale of 1 for a very pleasant odour to 7 for a very unpleasant odour
- The details of cloud and visibility at the time of their report

The odour sources were divided into four groups. These were odours from landfills, brickworks, agriculture and local sources. The local sources category was a wide-ranging one, which covered odours from diverse sources such as traffic, restaurants and take-away shops, gardening odours or local factories. The monitors could, if they wished, provide any other information to do with the odour or the environment at the time. This included how the odour smelled to them, if the odour changed or details of weather conditions. The monitors were supplied with notepads for recording their reports. The reports were sent to IERC on a monthly basis and were recorded in database form.

As discussed in Chapter 5, when the monitors' reports were examined, the standard of reporting was found to be extremely variable. Some monitors provided detailed reports providing all the information they could. Others did not, missing out information such as the time or the odour source. There were discrepancies between reports from monitors who were located in the same area. One monitor would report an odour, yet their neighbour would not. Did this discrepancy arise due to one monitor being at home and being able to smell the odour and the other either being unable to smell an odour due to their being away from home, being ill or indoors? Some monitors did state when they were away from home or ill, but others did not. This meant that the pattern of response was not made clear from the data. This problem of the supply of incomplete information led to changes in monitoring procedure being introduced in Spring 1997.

6.4 Recruiting new monitors and changes to monitoring procedure Spring 1997

After the data from the pilot panel had been examined and the research questions identified, steps were taken to recruit new monitors, obtain more detailed information about them and change monitoring procedure.

6.4.1 Recruiting new monitors

It was decided to select monitors in the settlements surrounding the two landfill sites in the Marston Vale. Other projects have selected monitors downwind in the direction of the prevailing wind of an odour source (Goldsmith 1973). However, this project sought to clarify the exposure of the whole community surrounding the landfill sites. This would include people living upwind of the sites who may experience odours, albeit infrequently. Additionally, as the project involved assessing community response to odour, different types of people would be included in the panel. Therefore the panel would consist of, for example, males and females, differing age groups and occupations. This is opposed to the design of a panel that would consist of one type of person, for example all male, of a particular age and so on. This type of panel would provide information on the response of that particular monitor type only.

There were constraints placed on the size of the panel due to the project budget. However, it was decided to increase the size of the panel to approximately 35 monitors for three months, before reducing numbers to around 25. The purpose for having a large number of monitors was to have a period of "intensive monitoring", an attempt to generate as much information as possible about levels of exposure to odour pollution. It was decided to retain monitors who were already monitoring and increase numbers to the required level. This would indicate if there were differences in reporting patterns between long-term and new monitors.

The numbers of monitors at each settlement were not strictly based on population size, although this did form the basis for numbers. Accurate population figures for all the settlements were not available and what figures were available showed the sizes to vary markedly. For example, Wootton has a population of approximately 4000, whilst Kempston Hardwick has a population of approximately 100. Therefore the results of the survey and previous monitoring results were also taken into account (see below). Complaints data were also considered as a factor, if only in that they showed no similarity to the distribution of results from the survey and monitors' reports. However, it was decided to have at least 4 monitors at Cranfield and Stewartby, as these were the locations where complaints had arisen.

An examination of results from the survey and earlier monitoring reports was made. The survey results were examined for the locations of respondents who had specifically referred to landfill odour. These references were then counted. The numbers are shown in Table 6.3 below. At the same time, a period of three months was selected randomly from the monitors' reports. Table 6.3 shows the most frequently and second most frequently reported odours at each location during this period. It can be seen that landfill odour was either the most commonly or second most commonly reported odour at every location. The percentages of reports of landfill odour at each location are shown in Table 6.4. As mentioned earlier all these factors were taken into account when monitor numbers were decided upon for each settlement.

It will also be remembered from Section 5.2 and Figure 5.2, that there was a rough split in reporting patterns across the Vale seen in the pilot panel results. Landfill odour was predominant in reports, together with brickwork odour, made by pilot panel monitors in the northwest to southeast of the Marston Vale. The settlements in this area included Kempston, Wootton, Kempston Hardwick, Stewartby and Marston Moretaine. Settlements found to the south of this line, Cranfield, Wootton Green, Brogborough and Lidlington did not show this pattern. This may suggest a link with the prevailing wind direction, blowing from the southwest, which would carry odour to settlements in the northeast. There was no apparent pattern associated with distance from the landfill or brickworks sites. Cranfield is close to the western margin of the landfill site (approximately 1.5 to 2km), and yet landfill odours were not the most commonly reported odour. Stewartby reported landfill odour most frequently (the village is 1km from Lfield), despite brickworks being present in the village.

Location	Number of survey references to landfill odour	Most frequently reported odour by panel	Second most frequently reported odour by panel	Proportion of landfill odour reports (%)
Brogborough	1	**Local sources**	**Landfill**	**27**
Cranfield	17	**Local sources**	**Landfill**	**40**
Kempston	3	**Brickwork**	**Landfill**	**25**
Kempston Hk.	2	**Brickwork**	**Landfill**	**12**
Lidlington	0	**Local sources**	**Landfill**	**35**
Marston M.	21	**Brickwork**	**Landfill**	**35**
Stewartby	5	**Landfill**	**Brickwork**	**70**
Wootton	7	**Landfill**	**Brickwork**	**45**
Wootton G.	2	**Brickwork**	**Landfill/Farm**	**25**

Table 6.3: Number of references to landfill odour in the 1993 Survey, most frequently reported odours at each monitor location and the percentage of landfill odour reports

However, the monitor at Kempston Hardwick reported brickworks odour more frequently, whilst the Lfield site is 1.25km away to the southwest. Monitors at Kempston reported both brickwork and landfill odour. They were located approximately 1 to 1.5km from the brickworks at Kempston Hardwick, but they were situated approximately 2km away from Lfield. When considering the relationship of orientation and distance from the odour source, there was the problem of not knowing the location of the monitor when they detected the odour. It is possible that they may not have been at home, but elsewhere in the Vale, but did not state this in their report. However these factors were borne in mind when finalising the selection of the numbers of monitors and designing the report sheets. It was decided to have larger numbers of monitors in the settlements located in the north-east of the Vale, where landfill odour was apparently most frequently detected. It was also decided to ask monitors where they were when they detected odours.

Summarising the criteria for monitor numbers at settlements in the Marston Vale:

- Population size – generally, the larger the settlement, the larger the number of monitors.

- The initial complaints made at Cranfield and, to a lesser extent, Stewartby indicated the need for a larger number of monitors at these settlements.
- The numbers of reports made by the pilot study monitoring panel – landfill odour was the most frequently or second most frequently reported odour at all settlements, indicating that all settlements be included in the study.
- The orientation of monitors to odour source – settlements in the northeastern half of the Vale were identified as producing high levels of landfill odour reports and therefore would need greater numbers of monitors.

Location	Preferred monitor numbers	Actual monitor numbers
Brogborough	3	2
Cranfield	4	4
Kempston	4	5
Kempston Hardwick	3	3
Lidlington	3	3
Marston Moretaine	5	1
Stewartby	4	5
Wootton	5	4
Wootton Green	3	3

Table 6.4: Preferred and actual monitor numbers used.

The monitor numbers chosen are listed in Table 6.4, along with actual numbers used. There were problems recruiting monitors at Marston Moretaine and Brogborough (discussed below) that meant that these two settlements had fewer monitors than required.

To recruit new members for the odour panel, it was decided to advertise using leaflets and reply-paid envelopes posted through doors of randomly selected addresses. The leaflet consisted of an advertisement on one side, asking for volunteers, and a letter providing more detail of the project and the work involved on the other. As an incentive, volunteers were paid £23 per month for monitoring. However, this was not overly stressed in either the advertisement and letter nor was the amount of payment disclosed. Payment was explained in greater detail at the meetings. The streets were randomly selected from a list of postcodes and then the houses were selected at random in those streets. The number of leaflets posted at each location depended on the number of monitors required and the expected response rate. It was estimated that the response rate to the leaflets would be approximately 10% (Punter 1987). Therefore if three monitors were required at a particular location, 30 leaflets would be delivered. The leaflets were delivered to all the locations during the middle of February 1997. The recruitment activities are summarised in Table 6.5.

The response to the leaflets varied greatly. It became apparent that while at some locations sufficient numbers of volunteers were coming forward, at others they were not. Two weeks after the first leaflet drop, reminder leaflets were posted to the same

Week	Activity	Comments
10 to 14 February	**First posting of leaflets at all locations**	**Response to leaflets poor except at Cranfield, Kempston H'wick & Wootton Green** **Waited 2 weeks before posting reminders**
24 to 28 February	**First set of reminders posted at Brogborough, Lidlington, Kempston, Marston, Stewartby & Wootton**	**Satisfactory response at all locations except Stewartby and Marston** **Waited 2 weeks before next posting**
10 to 14 March	**Posting of leaflets at second set of 25 addresses at Stewartby and Marston**	**Sufficient volunteers came forward at Stewartby, not at Marston** **Waited 2 weeks for reminders**
17 to 21 March	**First 4 meetings for volunteers held at IERC**	**All volunteers attend meetings**
24 to 28 March	**Reminder leaflets posted at second set of addresses and first posting at 20 more addresses at Marston** **Two posters at Post Office and Primary School at Marston** **Second set of 4 meetings for volunteers at IERC** **Letters go out to current monitors inviting them to meetings at IERC**	**No response to leaflets or posters at Marston** **Three volunteers fail to attend meetings** **Three current monitors drop out of panel**
7 to 11 April	**Meetings for current monitors at IERC** **Report sheets, guidance notes and envelopes sent out to all monitors** **All monitors telephoned before start of monitoring to ensure they have paperwork and know what to do**	
14 to 18 April	**Telephone calls to all monitors to identify any problems or queries about monitoring**	

Table 6.5: Timetable of activities to recruit monitors and reorganise the monitoring panel

addresses at the four villages with the poorest response. This brought forward two more volunteers at Wootton and one volunteer at Brogborough.

A second leaflet drop at 25 new addresses was carried out at Stewartby and Marston Moretaine. Sufficient numbers of volunteers then came forward at Stewartby, but not Marston Moretaine. Leaflets were delivered at an extra 20 addresses, bring the total number of selected addresses in Marston Moretaine to 95. At the same time as the third leaflet delivery, notices were posted at the Marston Moretaine sub-post office and the local primary school. Despite this effort, only one volunteer came forward.

The result of the leaflet campaign resulted in most settlements having sufficient monitors. However, this was not the case at Marston Moretaine where there was only one monitor. Additionally, the make up of monitors at the different settlements was not satisfactory. For example, at Kempston Hardwick and Brogborough there were only female monitors and there were no male part-time workers. It became apparent when the population response framework was developed that certain types of individual, such as males at Kempston Hardwick or Brogborough, or male part-time workers could not be included due to there being no monitors of this type to make odour reports.

Volunteers were invited to attend one of a series of meetings at IERC held during March 1997. At these meetings they were informed about the project background and what monitoring entailed. They were asked to complete a questionnaire (see 6.4.2) and to take the odour perception tests, as described in 6.3.1. Existing monitors were asked to attend a separate meeting held in early April. They were informed about how the project had progressed, about changes to monitoring procedure (see 6.3.2 and 6.4.4) and to retake the odour perception tests (see 6.3.4).

6.4.2 Additional information about monitors

It became apparent from the examination of monitors' reports during the pilot panel that there were gaps in information about their background and lifestyle that may explain some of the patterns that emerged from the data. For example, the most frequent times for complaints were around 8.00am, 3.00pm and 7.00pm. Was this due to lifestyle factors? People generally get up and go to work around 8.00am.

Therefore it is possible odours are reported then due to individuals being up and about at that time and being able to detect odour. Conversely, work may start at a local odour source, for example landfill sites, leading to odour release at that time. Also as referred to above, the volunteer monitors may have had differing sensitivity to odours due to factors such as age or occupation, which may have caused differences in odour reporting.

The identification of these patterns led to the research objectives first raised in Chapter 1, later in Chapter 4 and the development of the odour monitoring tree. The questions related to physical or environmental factors, physiological and behavioural factors. The questions are reiterated below (see Section 4.2),

- Firstly, to ascertain how personal factors, such as age or health can affect exposure levels of odour an individual can experience.
- Secondly, to ascertain how an individual's lifestyle and behaviour may influence their exposure to odour.
- Thirdly, to relate this information to spatial and environmental factors.
- Finally, to use the information obtained as a means of demonstrating that 'human factors' have to be included in odour assessment.

It should also be remembered that these questions have their basis in the four major components identified in Section 4.2, namely physical, physiological, psychological and behavioural components. The data from the monitors, it was hoped would provide information on the three 'human' components, physiology, psychology and behaviour. When examining the discussion in the previous paragraph, it can be seen that the questions posed fall within the scope of the three questions summarised above. It then became apparent that, in order to answer these questions that more information on the personal and behavioural attributes of the monitors was necessary. It was therefore decided to find out more about monitors' backgrounds, including their behaviour and factors affecting their sense of smell using two sources. These were a questionnaire asking for basic information about the monitor and a time diary (see Appendix A).

The Questionnaire

The questionnaire was very brief and simple so not appear be excessively intrusive and so it could be completed during the meetings. The questionnaire asked for details relating to several areas. These included age and health, details on occupation, likes and dislikes about the Marston Vale. As discussed in Chapter 2, it is known that these factors may affect or influence the ability to perceive odour and affect opinions of it. The questions are discussed in greater detail below. The questionnaire also asked for times when volunteers would be able to monitor, which was also useful in gaining some idea of the times when monitors were most likely to be at home.

- Questions 1 to 4 asked related to smoking habits. The volunteers were asked if they smoked, if they had given up smoking and were they exposed to smoking at home or at work. As discussed in 2.2.5, smoking and passive smoking can, according to some researchers, affect olfactory ability. If this is the case, then smoking was a lifestyle factor that had to be addressed as part of the second research objective.

- Questions 5 and 6 related to the volunteer's health (see 2.2.2 and 2.2.3). They included questions on age, volunteers were asked to state their age group, and if volunteers had any health problems that would affect their sense of smell. Volunteers stated to which age group they belonged, rather than their age. It was decided to ask this as some people may be reluctant to divulge their age. When the health question was designed, it was decided that a definitive list of conditions and medication would be too detailed for a questionnaire of this type. Also, as with age, some individuals may not like to reveal that they had a medical condition in these circumstances. Therefore it was decided to ask them if they had a medical condition which they believed, affected their sense of smell and give a few obvious examples, such as hay-fever. It was then left to the volunteer what they would say. Age and health fall in the category of the second research objective relating to physiological characteristics that may affect olfactory ability.

- Questions 7 to 10 related to the occupation of the volunteer. These questions, like those on smoking, relate to lifestyle factors affecting exposure to odour and therefore address the second question relating to how behaviour can influence exposure to odour. Volunteers were asked to state whether they were employed full- or part-time, or if they were economically inactive, for example, retired or a housewife. They were also asked what their job was, if they had one. They were asked to state if, in their own opinion if they were exposed to materials, such as dusts or solvents, and then if, in their opinion, their exposure to these materials was above average. The question relating to employment was asked in order to identify individuals most likely to be at home for comparatively long or short periods. That is what their potential exposure time would be. As discussed in 2.2.6, which describes how reporting behaviour may be affected by the length of time at home, it was hoped to identify if individuals varied in their reports due to their potential exposure time. The questions relating to exposure to materials that can damage olfactory ability sought to identify those individuals who may be affected by such exposure. This was discussed earlier in 2.2.5.

- The next question, which was not numbered on the questionnaire, asked which times that the volunteer would find most appropriate for monitoring. It also provided additional information on the times when monitors would be at home, as that was when they would be able to monitor. This would indicate when an individual would be most likely to be exposed to odours.

- The final questions, numbered 12 to 14, related to how long the volunteer had lived in the Marston Vale and what they liked and disliked about the area. The question on how long they had lived in the area was asked in order to estimate how much experience the individual had of living in the area and, therefore, how much experience of odour they had. This question related to Section 2.3, particularly 2.3.1 that discussed how experience and learning may affect odour perception and response. It was hoped to identify if the length of time spent living in the area would affect the reporting pattern of the monitors. The last two questions, relating to likes and dislikes of the area, were asked to identify if the volunteer disliked or had concerns about their local environment and odour pollution, particularly landfill odour pollution. Again, these questions sought to identify if the opinions of the individual to odours or the landfill would affect their reporting patterns. These questions also related to Section 2.3. All of these questions related to how behavioural and psychological factors could affect response.

<u>The Time Diary</u>
An additional way of obtaining information on the length of time a volunteer was likely to be exposed to odour was the use of a time diary. This is shown in Appendix A. Volunteers were asked to record their movements for one week. They recorded the

times they got up, times they left their home and returned, and the time they went to bed. Short periods of time, of about half an hour or less, they were away from home were not recorded. This was done so as not to make the reporting excessively demanding. It was decided to limit the record period to one week for convenience for volunteers, as this was a very demanding activity and the good will of monitors was important to the project. It was hoped, on a basic level, that the time diary would clarify the discrepancies in reports, where one monitor reported an odour but a neighbouring monitor did not. It was also hoped the diary would illustrate how behaviour, in this case times when monitors were at home, could affect exposure levels. Again, as with the questions on employment patterns and times for monitoring, it was hoped information from the time diary would help to identify how behaviour could affect exposure levels and response. This is related to the second research objective, namely how an individual's lifestyle and behaviour can affect their exposure to odour.

It became apparent that this simple time diary, whilst useful in some respects was not sufficiently detailed. Examining the diaries showed that certain monitors had reported odours and others at the same locations had not. There was the suspicion that they may not have been absent and therefore for some other reason had "missed" the odour. These other reasons could have included their other attributes and the opportunity to identify the importance of these attributes was missed. For this reason, monitors should have been required to note all their absences no matter how brief.

6.4.3 The decision not to train the Odour Monitoring Panel

It was suggested that monitors could be taken to the local landfill sites in order to smell the odour produced at source. This idea, although initially an attractive one, was rejected for the following reasons.

- Firstly, on the day of the visit the odour that may be present may be being released from an atypical source, for example an unusual waste being disposed of at the site. This may cause confusion as to what the usual landfill odour is.
- Secondly, the properties of the odour may be different at source to what is experienced by the community some distance away. For example the intensity of the odour or its hedonic qualities may be different. As discussed in Chapter 4, this may arise due to dilution of the odour plume or the plume's constituents undergoing chemical reaction. Diaper (1987) referred to this phenomenon occurring in his study of the impact of farm waste odours. This may serve only to confuse monitors.
- There is also the possibility that the landfill would not smell when the visits took place, resulting in a wasted journey.

An additional factor to consider is the one proposed by Cain (1980) and Leonardos (1980) in their discussions on odour thresholds and panelist selection respectively. Cain questions whether trained odour monitors would produce results representative of the general population or if results could be biased in some way. Leonardos states a similar argument. He wrote that it is "recognised that sensitivity to odours...increases with training". The research wanted to identify the population exposure to odour, not just the monitors. If training resulted in monitors being more sensitive and producing higher numbers of reports, then this would make correlating the data to the general population difficult. It was therefore decided that the project would rely on the experience of the monitors of what they believed to be landfill odour at their location. This was more appropriate than their having to guess if the odour they smelled was similar to that which they smelled at the landfill site.

6.4.4 Changes to monitoring procedure

The reasons for changes made to monitoring procedure were discussed in Chapter 4 and in earlier sections of this chapter. The variation in the standard of reporting was quite marked. Some monitors provided detailed records, but others did not. At the meeting attended by long-term monitors, it became apparent that there was some confusion as to how monitoring should be done and what should have been reported. Some monitors did not know that they should report all odour types or that they could report odour more than once a day. In an effort to produce a more consistent standard of reporting, several new features were introduced. These were report sheets for daily recording, notes for guidance for monitors and a set time for monitors to sniff the air for odours.

A copy of the record sheet and guidance notes are shown in Appendix A. The record sheets were designed to take the form of a list, so monitors could scan the questions and place the answers beside them. This was done to ensure that all the details required would be provided. The questions asked were largely the same as during the earlier monitoring period, for example the time of monitoring and odour type and pleasantness. However, new questions were added to the list to obtain more information about the situation that odour pollution occurred in.

- At the top of each sheet, the monitors were asked to write their name and address. It was noted that monitors in the pilot panel did forget to write this information.

- Question 1 asked the monitors to write the date. Again, monitors did on occasion forget to write this in the pilot study.

- Questions 2 and 3 were not asked in the pilot panel. These were location and activity of the monitor at the time when they smelled the odour. The location referred to where the monitor was, for example indoors or outdoors, at home, at work, in the car and so on. They were asked to describe their activity at the time, for example were they monitoring, doing housework, watching television, or waiting for a bus. As discussed in Chapter 2, the lifestyle of the monitor and their location may influence their exposure to odour (research objectives 2 and 3). It was hoped to identify how frequently individuals would report odours whilst inside or outside buildings, and if they were actively monitoring or otherwise occupied. Question 4 asked the time that the report was made. Again, monitors did forget to report this in the pilot study.

- Question 5 asked the length of time that the monitor could detect the odour. In 2.2.7, there was reference made to adaption, where an individual will cease to smell an odour even though it is present in the environment. However, opinion appeared to be divided about how much emphasis should be placed on this process. It was hoped to identify if monitors did cease to detect odours after a brief period of minutes or if they could detect the odour for prolonged periods. If odour was found to be detectable for longer periods, then this may indicate that the potential for nuisance would be greater than if the odour was present only fleetingly.

- Question 6, asked for details of cloud cover. This question was asked during the pilot study and the categories used were the same. The question was asked to gain some idea of weather conditions at the time of the odour event. It would also be used for comparison with other monitors reports to assess their accuracy (see 6.4.5). As with other questions on the report sheet monitors were instructed at the meetings as how to estimate cloud cover. Instructions as to how to estimate cloud cover were also provided in the guidance notes for monitors (see Appendix A). The monitors were asked to look at the sky when they were making their report and select from a scale of 1 for clear sky to 8 for fog/drizzle the most appropriate description for weather conditions at the time of the report. Each point on the scale was touched upon and examples given. For example, "high/light clouds described in code 2, were described as "mares tails" (cirrus) or mackerel sky (cirrocumulus or altocumulus) clouds. The definitions of different forms of cloud cover were described in layman's terms, so as not to confuse individuals without a great deal of knowledge of differing types of cloud. Also, as with reporting odour properties, they were advised to select the best description they could, but if they were uncertain as to what to write, they could mention this in the space marked "any comments" on the record sheet.

- Questions 7, 8, 9 and 10, related directly to the odour. The monitors were asked what they thought the odour source was (Table 5.4 question 7). They had a choice of four categories, which were local, landfill, brickwork and agricultural odours. They then had to state how certain they were of their choice (Table 5.4 question 8). If they were very certain, they gave their choice a score of 1, if they were not very certain they gave it a score of 3. Some monitors at the meetings expressed concern that they would make the 'wrong' choice when describing odour, but were advised if they were very unsure to score their choice with a 3. They were also asked to state how pleasant and intense the odour smelled to them (Table 5.4 questions 9 and 10). They were asked to mark the pleasantness and intensity on a scale of 1 to 7. A score of 1 meant the odour was very pleasant or very weak, a score of 7 meant the odour was very unpleasant or very strong.

- There was a space left on the report sheet where the monitors were also invited to provide any information they felt was relevant, for example they could make a comment about the weather or the circumstances that they smelled the odour in. Some monitors in the pilot study did volunteer information, and it was thought appropriate to invite them to make their own contribution to monitoring.

At the meetings held at IERC, the volunteers were taken through the reporting sheets step-by-step and told what was required in the reports. It cannot be overstressed how thoroughly the process of monitoring and completing report sheets was examined. The meetings were deliberately made informal so as to put volunteers at their ease and enable them to ask questions about aspects they did not understand. In a further effort to ensure that monitors knew what to do, they were provided with guidance notes that provided step-by-step instructions on how to complete the recording sheets. Specimen notes are included in Appendix A. The notes also provided additional information such as what to do with completed sheets and contact telephone numbers in case of emergency. Also, as mentioned in 6.4.1, prior to the start of monitoring and two weeks after monitoring started, telephone calls were made to monitors to ensure that they understood the notes and how to complete their sheets, and were not having problems with monitoring.

It was decided to have as many monitors as possible sniff for odours at the same time in order to obtain as complete a picture of any odours at that time as possible. The time chosen was 8.00am, when all but two of the monitors were usually at home. It should be remembered that 8.00am was also one of the peak times for odour reporting. Therefore, the monitoring involved the monitors sniffing for odours once a day at the set time. They then completed their report sheets stating if they had smelled an odour or not. Obviously, if they did not smell an odour, the monitor could not answer all the questions, but it was important for them to state that they had not smelled anything. For the same reason, they were asked to record when they had not been able to monitor, due to sickness or holidays. As discussed in Chapter 5 and earlier sections in this chapter, missing reports had posed a problem with estimating exposure to odour and frequency of odour events. They were also asked to report any other odours that they may smell during the course of the day. This was the reasoning for the two columns for odour reports on the recording sheets.

There were some shortcomings with the reporting sheet that became apparent after the monitoring period. The monitors were asked to state their activity and location at the time of their report. For example, were they indoors or outside, monitoring or doing some other activity, were they at their home address or away from their settlement. Most monitors did state this, although some did not. This made analysing the circumstances surrounding the detection of odour difficult. There appears to have been some confusion also about how to go about recording the intensity and pleasantness/unpleasantness of the odour detected (although this result may have been due to an idiosyncratic sense of smell). This resulted in the inability to analyse any links between monitor types, location and odour hedonics (see Section 9.6).

6.4.5 Inspection of the data

When the monitors submitted their reports, the information contained within them was broken down on the level of the individual monitor and the groups of interest. It became apparent that the level of variation between individuals was very marked. The variation was such that it became apparent that grouping monitors by attribute was an artificial action to take as monitors with the same or similar attributes varied markedly in the reports they made (see Chapter 10). However it was decided to continue with the process of grouping for two reasons. Firstly because such attributes had been identified as affecting olfactory ability by other researchers. Secondly it was undertaken for the purpose of identifying a framework within which a response model could be developed. Grouping of monitors was undertaken by breaking down reports on the basis of age, gender, health, smoking habits, working pattern, length of time monitoring, length of time living in the Marston Vale and opinions of the Vale. Statistical tests were carried out where appropriate. The data were also broken down on the basis of temporality and spatiality, that is odour reported, time and monitor location. This was carried out to ascertain if there were particular times or places that were associated with odour pollution. The location of monitors when they made landfill odour reports were compared with wind direction to assess if they were downwind of the landfill site at the time of the report. In order to identify any relationship, the reports were also compared to wind speed.

It was also decided to attempt to validate the reports by comparing values of cloud and visibility assigned by monitors when they reported odours at around the same time. It was hoped to identify any individual who may have been inaccurate when their reports.

6.4.6 The post-monitoring questionnaire

At the end of the three months of monitoring, five of the monitors left the panel. They were invited to complete a second questionnaire asking them for details that could not be asked prior to monitoring. This is shown in Appendix A. This was because they could not answer the questions until they had monitored or, secondly, because it was felt the questions were of a sensitive nature and may have 'primed' their reports. The questions fell into three main categories. These were firstly, about monitoring, secondly, the results of their monitoring and, thirdly, information about complaints and their response to odours. Four monitors completed and returned the reports.

The first group of questions, numbers 1 to 4, related to the monitoring undertaken by the monitors. They were asked how easy it was to monitor and if they had any problems (Questions 1 to 3). They were also asked why they had volunteered to monitor (Question 4). These questions were designed to ask for feedback on monitoring to identify if any further changes should be made. Monitors were asked why they had volunteered in order to identify any individuals who were dissatisfied with the presence of the landfill or with the quality of their environment.

The second group of questions, numbers 5 to 9, asked the monitors their opinions about their reports. They were asked if they reported all odours or any specific odours more or less frequently than they anticipated (Questions 5 to 7). They were asked this in order to see if they were surprised with their results, for example if they reported odours less often than they had thought they would (Question 8). They were also asked if they were more aware of odours than before the start of the study (Question 9). This would help clarify if these individuals could be used in any further study or if they would be influenced into over or under reporting by their work on the panel.

The third group of questions, numbers 10 to 15, asked them if they had ever complained about odours and if, when they smelled odour had they ever taken avoiding actions or had medical symptoms due to their exposure. They were asked this to identify individuals who possibly had volunteered as panel members due to annoyance with odour. They were also asked if they wanted to make any other comments about the project or about their local environment.

6.5 The panel background

The panel consisted of 30 individuals at the start of monitoring. The panel was smaller than what was sought, due to the difficulty of finding individuals willing to monitor. Additionally, the numbers of individuals in each group were not always ideal. For example, there were 30 monitors in all, but only eight of them were male. It would have been preferable to have a larger number of males in the panel, as the sample size was very small. The details of the panel, obtained from the pre-monitoring questionnaire, are as follows,

- There were 22 female and 8 male volunteers
- There were 3 smokers amongst the monitors, and 6 monitors who had given up smoking between 3 and 36 years before monitoring. Seven monitors experienced passive smoking either at home or at work.
- There were 8 people in the 18-35 group, 7 people in the 36-45 group, 11 people in the 46-55 group and 4 in the over 55 age group.
- Two monitors stated that they suffered from hay-fever, one from allergies and another from asthma.
- Five of the monitors were housewives/carers and three were retired. Fourteen monitors were in full-time employment and 8 in part-time work.
- Two monitors stated that they were exposed to higher than normal levels of dusts or chemicals through their employment.
- The monitors were also divided into groups on the basis of how long they had lived in the Marston Vale. Nine had lived in the area for up to 5 years, 6 between 6 to 10 years, 7 for 11 to 20 years and 8 for over 20 years.
- The monitors, when completing their questionnaire, were asked to state 3 features of their local area that they did not like. There were 51 responses where the monitors expressed dissatisfaction with their environment. This ranged from traffic to litter. There were 12 instances where people referred to odours generally, 16 instances where they referred to the landfill sites as being undesirable and 3 statements about disliking landfill odour.

A summary of monitors' attributes is shown in Table 6.6 overleaf.

Monitors were located at 9 villages throughout the Marston Vale (see map in Figure 5.1). The numbers varied between settlements, from 1 monitor at Marston Moretaine to 5 at Cranfield, Kempston and Stewartby. Again, due to difficulties in recruiting monitors, there were settlements, such as Marston Moretaine, where monitor numbers were less than desired. The numbers of monitors are shown in Table 6.7.

monitor	gender	age	health problem	smoking habit	work pattern	lived in Vale (years)	new or long term
CCB	F	36-45	none	passive	Part-T	11	lo
VHB	F	18-35	none	passive	EI	8 5	new
CEC	F	36-45	none	non-smo	Part-T	16	lo
NHTC	F	18-35	none	non-smo	EI	32	new
BJC	F	36-45	allergies	non-smo	Part-T	3	new
MKC	M	56+	none	none	Full-T	18	new
PEK	F	36-45	hay-feve	non-smo	Part-T	15	lo
PFK	F	46-55	none	non-smo	Part-T	26	lo
MHK	F	46-55	asthma	non-smo	Full-T	26	new
KSK	F	36-45	none	non-smo	Full-T	14	new
TSK	M	46-55	none	non-smo	Full-T	20	new
IFKH	F	46-55	none	non-smo	Full-T	7	new
CMKH	F	46-55	none	smoker	Full-T	1	new
SWKH	F	18-35	none	passive	Full-T	1	new
NCL	F	18-35	none	non-smo	Full-T	7	new
CJL	F	46-55	none	non-smo	EI	14	lo
DKL	M	46-55	none	non-smo	Full-T	4	new
MHMM	F	56+	none	smoker	EI	3	new
KBS	M	56+	none	smoker	EI	26	lo
CBS	M	18-35	none	passive	Full-T	5	new
CFS	F	36-45	none	non-smo	Full-T	7	new
SJS	F	18-35	none	non-smo	Part-T	35	lo
SWS	F	18-35	none	passive	Full-T	4.5	new
PCW	M	56+	none	non-smo	EI	1	new
LRW	F	46-55	none	non-smo	Full-T	10	new
ERW	F	46-55	none	passive	Part-T	23	lo
JSW	M	46-55	hay-feve	non-smo	EI	50	lo
BLWG	F	18-35	none	non-smo	Part-T	12	new
FLWG	F	46-55	none	non-smo	EI	23	lo
SRWG	M	36-45	none	passive	Full-T	2.5	new

Table 6.6: Summary of monitors' details

Key to Table 6.6:
Gender: F = Female, M = Male
Smoking: passive = passive smoker, non-smo = non-smoker
Work pattern: Full-T = full-time, Part-T = part-time, EI = economically inactive
New or long-term monitor: new = new monitor, lo = long-term monitor

Location	Number of monitors
Brogborough	2
Cranfield	4
Kempston	5
Kempston Hardwick	3
Lidlington	3
Marston Moretaine	1
Stewartby	5
Wootton	4
Wootton Green	3

Table 6.7: Numbers of monitors at different locations throughout the Marston Vale

The monitor groupings form the basis of the analysis in Chapters 7 and 8, and the development of the framework of population response. The results from the panel were broken down into these groups for the data analysis in order to assess any variability in response.

6.6 The results of the odour trials

As discussed in Section 6.3 the odour trials were conducted in meetings for panel volunteers prior to the start of monitoring in April 1997. All the volunteers, whose backgrounds are related above, took part in the trials. The individual results are summarised in Table 6.8. The scores for each test are out of a maximum of 5 points.

As will be remembered from Section 6.3, there were three tests, for discrimination between different odours, and tests to discriminate different intensities and thresholds. There were five stages in each test. It can be seen from Table 6.8, that the results were apparently variable. Four monitors, BJC, KSK, CMKH and DKL, reported having colds and blocked noses at the trials. However, it is not clear how this may have affected their results, if at all. They did produce variable results, although none of them got all the tests completely correct.

It should be remembered from Section 4.2 that the first research question asked how personal factors such as health or age may affect exposure to odour. Such factors are known to influence detection and identification of odour. This was discussed further in Section 5.2, where the data analysis from the pilot study had suggested that such factors as age and gender might have affected reporting patterns. Therefore in order to gain some insight into the monitors' reports the results in Table 6.8 were examined on the basis the physiological attributes of the volunteers. These attributes are gender, age, smoking/non-smoking and health, which are believed to affect the ability of an individual to sense an odour.

Volunteer	Discrimination test - number correct	Threshold test - number correct	Intensity test - number correct
CCB	5	2	2
VHB	5	5	5
CEC	5	3	3
NHTC	5	5	5
BJC	2	4	1
MKC	5	4	5
PEK	5	4	2
PFK	5	2	3
MHK	2	5	3
KSK	3	3	1
TSK	4	5	3
IFKH	3	5	2
CMKH	5	5	1
SWKH	5	5	5
NCL	5	5	5
CJL	5	2	3
DKL	3	4	5
MHMM	4	3	1
KBS	5	3	3
CBS	5	5	3
CFS	5	5	3
SJS	2	3	3
SWS	2	3	3
PCW	5	5	5
LRW	5	5	5
ERW	3	3	3
JSW	5	3	3
BLWG	5	5	5
FLWG	3	4	3
SRWG	2	4	1

Table 6.8: The results of the odour trial for each volunteer

The first attribute to be examined was that of gender. The mean scores of male and female volunteers were 4.25 and 4.04 respectively. These values did not appear to be greatly different. A *t*-test was carried out which produced a value of 0.28. The critical value of 0.92 was greater than the test value. This meant that the null hypothesis, i.e. that there was no significant difference between the means, was accepted.

The other attribute for which a *t*-test was carried out was that of health, where volunteers were divided into two groups. These were people with health problems that could affect their sense of smell and those without such problems. The *t*-value was

0.43 and the critical value was 3.0. Again, as with age, the null hypothesis, that there was no significant difference between the two groups, was accepted.

An Analysis of Variance was carried out for both age and smoking. The F-value for age was 2.28. As the critical value was 3.01, the null hypothesis, that there was no significant difference between the different age groups was accepted. The F-value for smokers, non-smokers and passive smokers was 4.01. As the critical value was 3.01, the null-hypothesis, that there were no significant differences between the groups, was rejected and thus there were significant differences between the groups. The mean score for non-smokers was 11.55, passive smokers was 10.86 and for smokers was 10. This suggests that non-smokers had slightly greater olfactory ability than passive smokers who in turn had slightly higher sensitivity than smokers did.

To summarise, there were several results from the trials.

- The results of the trials showed that there was some variability in the sense of smell of the individual volunteers. Four volunteers, BJC, KSK, CMKH and DKL reported having problems with their sense of smell at the trials. How this affected their results is not known.
- Statistical tests showed no significant differences between volunteers on the basis of gender, age or health. However, tests for the effect of smoking on trial results did produce a result showing significant difference.

There was no testing to identify the ability to detect odour pleasantness or unpleasantness. As referred to above, there was a problem with one monitor in particular recording odour hedonics properly. This may have arisen to his having an idiosyncratic sense of smell, but this was not identified.

6.7 Summary of Chapter 6

As stated above, a new monitor panel commenced work in April 1997. Whilst at introductory meetings, the monitors took part in odour perception tests and completed questionnaires on their backgrounds. These tasks were carried out to identify the volunteers' olfactory attributes and to gain some insight into factors that would affect their olfactory ability and behaviour. For the first week of monitoring, they completed diaries recording when they were absent from home, so that the times and lengths of time they could be exposed to odour could be estimated. The monitors used recording sheets for their daily reports. The panel was made up of 30 people who monitored for three months. The monitors' backgrounds were ascertained through the use of the pre-monitoring questionnaire and are recorded in Table 6.6. The monitors were not trained as this may have caused bias in the results and would have made linking the results to the general population of the area difficult.

It was hoped these activities would provide information on the following,

- To provide information on the exposure and detection and response on the level of the individual (research objective 2, see Section 7.2).

- To provide information on the level of groups of individuals with similar attributes (research objective 2, see section 7.3).
- To identify patterns of landfill odour impact on a spatial and temporal basis (research objective 3, see Section 8.2).

On the basis of these activities, the next stage would be,

- To attempt to develop a framework on which a population response model could be based (research objective 1, see Chapter 10).

Chapter 7

Exploring variety of response to odour

7.1 Introduction

Chapters 7 and 8 relate the results obtained from the monitoring panel in operation from April to July 1997. This chapter examines monitors' reports on the level of the individual monitor and groups of monitor with attributes in common. Chapter 8 examines reporting patterns on the basis of communities and locations.

Section 7.2 highlights variability in reporting patterns produced by individual monitors. This variability is shown to be substantial with no overall patterns observed in monitors' reports. This suggests that the patterns of exposure and response observed in the panel are the product of the interaction of a number of attributes and factors such as time and location, rather than these factors operating independently. In Section 7.3, despite this substantial variation, the reporting patterns of monitors grouped by similar attributes are examined. The attributes are those identified in Section 2.2 that may affect the ability to detect and respond to odours. They include gender, age, health and working patterns. As mentioned in Section 6.4, this was undertaken for two reasons. Firstly because such attributes are believed to affect olfactory ability. Secondly, because such groupings form the basis of the prototype response framework. It was decided that the development of the framework could still be undertaken as a demonstration of how such a procedure could be done. The results of this analysis of groupings were tested for statistical significance. Even though some of the results were not found to be significant, the groupings were still used as the literature suggested that there would be differences. The information used for this procedure was obtained from the pre-monitoring questionnaire (see 6.4.2). These groupings were selected so as to facilitate the development of the population response framework in Chapter 10, which endeavours to estimate exposure to odours for different types of individual at different locations. It is recognised that the framework is crude and unable to embrace the great variation in exposure and response seen amongst individual monitors. Indeed, Sections 7.2 and 7.3 illustrate that the experience of odour pollution can differ substantially across a population due to personal attributes and spatial and temporal factors (research objectives 2 and 3). However, the framework does attempt to address some of the interaction of attributes observed at group level. In Chapter 9, where report reliability is assessed, the reporting patterns of monitors on the individual and group level were examined. This was undertaken to identify individual monitors whose reports deviated from the usual pattern of reports.

7.2 The reporting patterns of individual monitors

This section discusses the variability seen in the reports of individual monitors of the odour panel. Table 7.1, reproduced from Section 6.5, summarises the individual monitors' details. Figure 7.1 shows a breakdown of the numbers and types of odours produced by the monitors at each location. Figure 7.2 shows the reporting intensity

Monitor code name	gender	age	health problem	smoking habit	work pattern	lived in Vale (years)	new or long term
CCB	F	36-45	none	passive	Part-t	11	lo
VHB	F	18-35	none	passive	EI	8.5	new
CEC	F	36-45	none	non-smo	Part-t	16	lo
NHTC	F	18-35	none	non-smo	EI	32	new
BJC	F	36-45	allergies	non-smo	Part-t	3	new
MKC	M	56+	none	non-smo	Full-t	18	new
PEK	F	36-45	hay-fever	non-smo	Part-t	16	lo
PFK	F	46-55	none	non-smo	Part-t	26	lo
MHK	F	46-55	asthma	non-smo	Full-t	26	new
KSK	F	36-45	none	non-smo	Full-t	14	new
TSK	M	46-55	none	non-smo	Full-t	20	new
IFKH	F	46-55	none	non-smo	Full-t	7	new
CMKH	F	46-55	none	smoker	Full-t	1	new
SWKH	F	18-35	none	passive	Full-t	1	new
NCL	F	18-35	none	non-smo	Full -t	7	new
CJL	F	46-55	none	non-smo	EI	14	lo
DKL	M	46-55	none	non-smo	Full-t	4	new
MHMM	F	56+	none	smoker	EI	3	new
KBS	M	56+	none	smoker	EI	26	lo
CBS	M	18-35	none	passive	Full-t	5	new
CFS	F	36-45	none	non-smo	Full-t	7	new
SJS	F	18-35	none	non-smo	Part-t	35	lo
SWS	F	18-35	none	passive	Full-t	4.5	new
PCW	M	56+	none	non-smo	EI	1	new
LRW	F	46-55	none	non-smo	Full-t	10	new
ERW	F	46-55	none	passive	Part-t	23	lo
JSW	M	46-55	Hay-fever	non-smo	EI	50	lo
BLWG	F	18-35	none	non-smo	Part-t	12	new
FLWG	F	46-55	none	non-smo	EI	23	lo
SRWG	M	36-45	none	passive	Full-t	2.5	new

Table 7.1: Summary of monitors' details

Key to Table 7.1
Gender: F = Female, M = Male
Smoking: Passive = passive smoker, non-smo = non-smoker
Work pattern: Full-t = Full-time, Part-t = Part-time, EI = Economically inactive
New or Long term monitor: new = new monitor, lo = long-term monitor

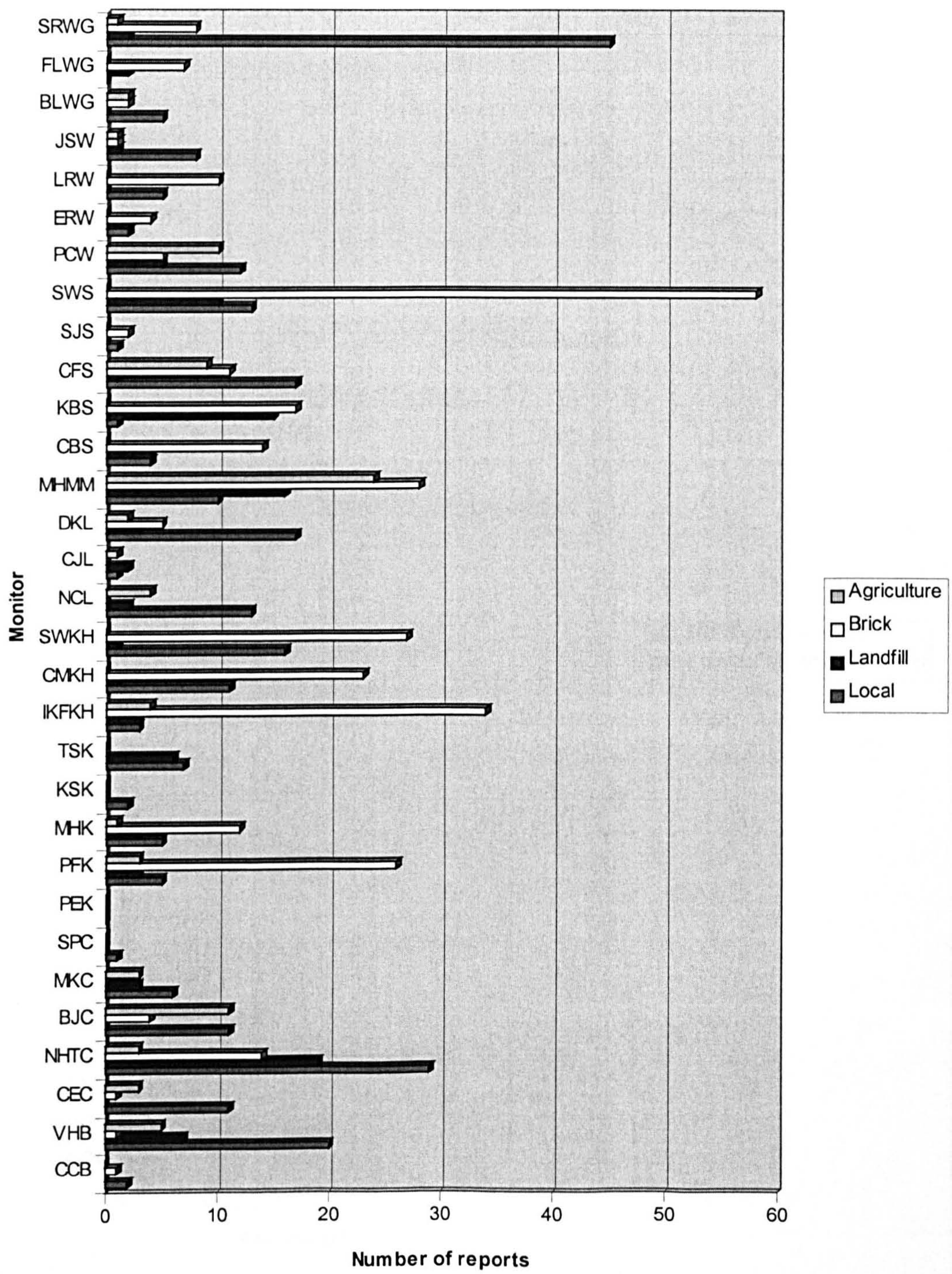


Figure 7.1: The breakdown of reports made by individual monitors by perceived source of odour

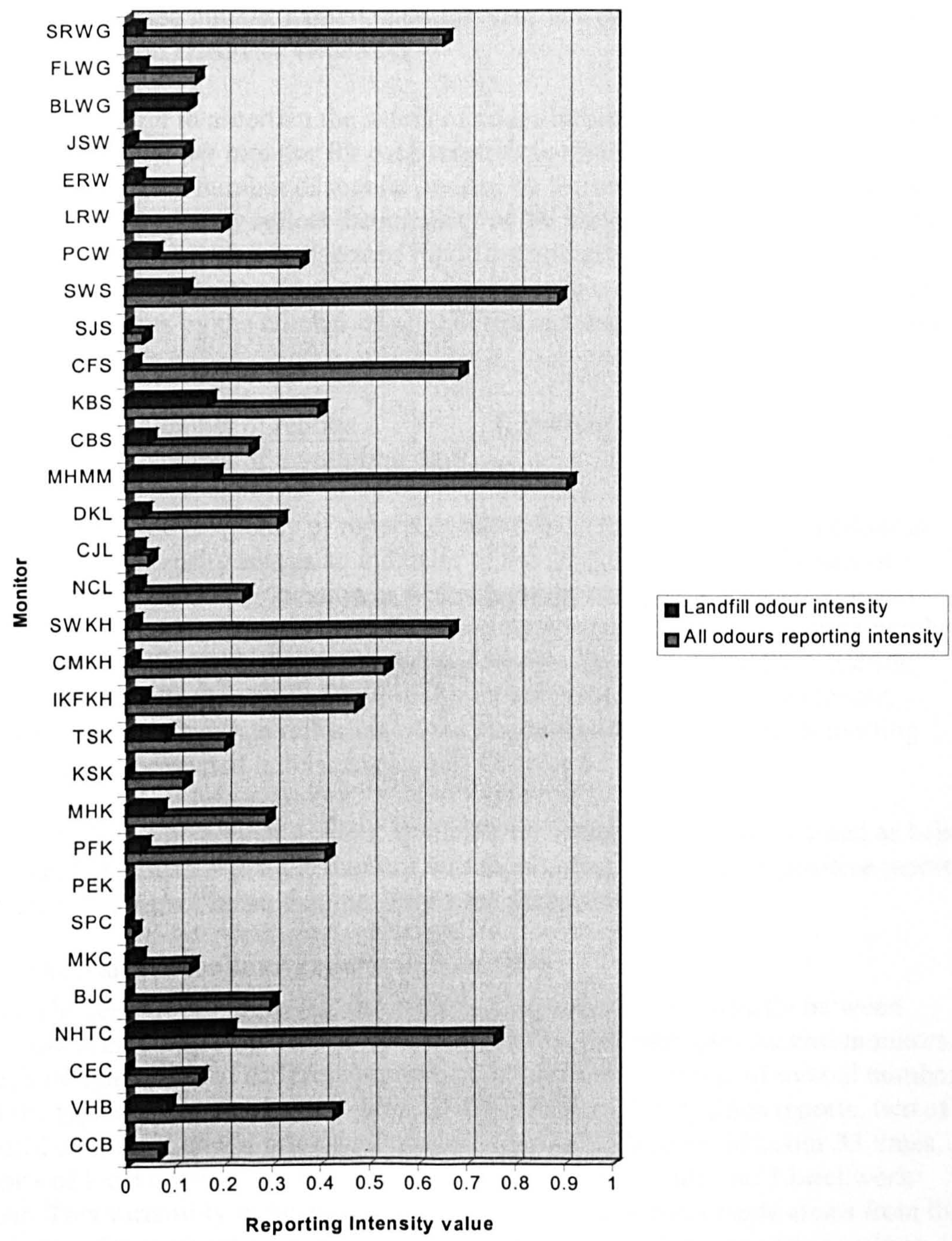


Figure 7.2: Landfill reporting intensities for each monitor compared to overall reporting intensities

for all odours and for landfill odours for each monitor. Each monitor is referred to by a code name to ensure anonymity. The first two letters are the monitors' initials and the last one or two letters are the initials of their location, for example 'WG' refers to Wootton Green and 'C' to Cranfield. For example, monitor VHB was monitor VH at Brogborough and monitor CMKH was monitor CM at Kempston Hardwick. Two monitors had three initials, namely monitor NHT at Cranfield (NHTC) and monitor IKF at Kempston Hardwick (IKFKH).

An initial attempt to ascertain the extent of odour nuisance was to calculate the mean number of reports per monitor for each location or monitors found within each attribute group (the number of reports divided by the number of monitors). However, this does not adequately reflect the intensity of the impact of odour experienced by monitors. Therefore what was termed reporting intensity was calculated. This intensity value, taking the form of a weighted average, is obtained by dividing the number of reports by the number of actual days monitors were active at a particular location.

So:
$$\frac{\text{Number of reports}}{\text{Number of monitoring days}} = \text{Reporting Intensity}$$

This identifies the frequency of reports or odour incidents, i.e. how often odour is reported. The intensity acts as an indicator of the frequency of odour impact on individuals at a particular location or within a group and makes it easier to make comparisons of data obtained from different locations or groups by different numbers of monitors producing different numbers of reports. By calculating the reporting intensity value, the numbers of days monitors are present is taken into account, providing a more accurate reflection of the frequency of odour events. Reporting intensities are presented in this chapter and Chapter 8.

It should also be noted that where a monitor's reporting intensity is recorded as being zero, i.e. 0.0, it means that the monitor was monitoring, but made no positive reports of odour. It does not mean that that they were not monitoring.

7.2.1 Individual monitors' reports and location

As can be seen from Figure 7.1, the pattern of reports varied markedly between monitors even when they were at the same location. For example, the two monitors at Brogborough produced differing reporting patterns, both in terms of overall numbers and the types of odours reported. Monitor CCB produced only three reports, two of landfill odour and one of brickwork odour. Monitor VHB reported odour 33 times, 20 reports of local odour, 7 of landfill odour, 5 agricultural odours and 1 brickwork odour. This variability in the numbers and nature of the reports made arises from the attributes of the individual monitor. Monitor CCB belonged to age category 36 to 45 years, worked part-time and was a long-term monitor. The reporting intensities for these three groups were comparatively lower than other groups. Monitor VHB was younger, in the 18 to 35 year category, was a housewife and was a new monitor. These groups produced higher reporting intensities (see Sections 7.3).

Figure 7.2 shows the reporting intensities for each monitor. It can be seen that the reporting intensities for "all" odours and landfill odour also vary markedly, even between monitors at the same location. The monitors at Brogborough produced different reporting intensities, 0.067 for CCB and 0.427 for VHB. Such variability occurred at other locations, such as Cranfield. Monitor NHTC had high reporting intensities for all odours and landfill odours, 0.758 and 0.209 respectively.

Other monitors at the same location did not produce such high values for either category. Monitor CEC produced intensities of 0.15 for all odours and 0.0 for landfill odours, monitor BJC 0.297 for all odours and 0.0 for landfill odour and MKC 0.132 and 0.024 for each group respectively. These variable results were produced by monitors living at the same location, and illustrate how the experience of odour can differ between individuals. As reporting intensities are discussed further below, the intensity values for all monitors are shown in Table 7.2. It can be seen that not only do reporting intensities between monitors at the same location vary, but also reporting intensity values between monitors in the same attribute groups, such as gender or age.

7.2.2 Individual reports and gender

Referring to Table 7.3, the male monitors produced different intensity values for all odours and landfill odours. Monitor SRWG produced the maximum reporting intensity value of 0.654 for all odours, whereas monitor JSW produced the minimum value of 0.121. Additionally, when a monitor produced a high reporting intensity for one odour type, either all odours or landfill odours, it did not necessarily follow that they produced a similar reporting intensity level for the other odour type. For example, monitor SRWG produced the highest reporting intensity value for all odours for male monitors, but produced one of the lowest values for landfill odours.
The maximum value of landfill odour reports of male monitors was produced by KBS, the minimum value again was produced by JSW (JSW produced the lowest reporting intensity values for both odour groups). He was a long-term monitor who had health problems that may have affected his ability to detect odours. Wootton, the settlement where JSW lived, produced the fourth highest reporting intensity value for all odours (0.34), but one of the lower values for landfill odour (0.018). Therefore, it may not be surprising that he produced a lower value for landfill odour reports, but it is surprising that he did not produce a higher value for all reports. Possibly, the factors identified above affected his reporting pattern. The landfill odour reporting intensity value for KBS of 0.169 should not be surprising, considering his proximity to the Lfield site. SRWG produced a high reporting intensity value for all odours, which reflects the high level of local odour reports he made. Similar variations were observed amongst female monitors. It is notable that females produced wider ranges than males in reporting intensities for both all odours and landfill odours, although this may be a product of there being more females than males in the panel. Monitor MHMM produced the highest reporting intensity for "all odours" (0.909), and PEK (0.0) the lowest. The maximum reporting intensity value for landfill odours was 0.209, produced by NHTC and there were a number of female monitors who had reporting intensity values of 0.0 (CCB, CEC, BJC, PEK, KSK, SJS, LRW, BLWG).

Monitor PEK failed to produce any reports. Why this should have occurred is not clear. She was a long-term monitor who had health problems, which may have lead to her having reduced reporting intensity values. However, to fail to report any odours at all, even local odours, is extraordinary. Perhaps she simply illustrates reporting fatigue, that is a loss of motivation to report odours. If this is the case, she demonstrates the importance of close examination of monitor performance with time. Monitor PEK had the smallest variation in the intensity values for both odour types.

The monitor with the largest range was MHMM with an overall odour reporting intensity value of 0.909 and a landfill odour intensity value of 0.182. Both of these intensity values were very high, the difference between them being the result of MHMM producing high levels of brickwork and agricultural odour reports. Marston Moretaine is a settlement where any odour type would be likely to be detected. It is located at the centre of the Vale, close to Lfield, Stewartby brickworks and agricultural and local odour sources. The variation between male and female monitors is summarised in Table 7.4.

Monitor	Reporting Intensity for all odours	Reporting Intensity for landfill odours
CCB	**0.067**	**0.000**
VHB	**0.427**	**0.085**
CEC	**0.150**	**0.000**
NHTC	**0.758**	**0.209**
BJC	**0.297**	**0.000**
MKC	**0.132**	**0.024**
PEK	**0.000**	**0.000**
PFK	**0.411**	**0.033**
MHK	**0.289**	**0.066**
KSK	**0.118**	**0.000**
TSK	**0.203**	**0.081**
IKFKH	**0.472**	**0.033**
CMKH	**0.532**	**0.013**
SWKH	**0.666**	**0.016**
NCL	**0.241**	**0.024**
CJL	**0.047**	**0.023**
DKL	**0.314**	**0.035**
MHMM	**0.909**	**0.182**
CBS	**0.256**	**0.046**
KBS	**0.397**	**0.169**
CFS	**0.687**	**0.016**
SJS	**0.036**	**0.000**
SWS	**0.890**	**0.121**
PCW	**0.360**	**0.058**
LRW	**0.200**	**0.000**
ERW	**0.122**	**0.024**
JSW	**0.121**	**0.011**
BLWG	**0.130**	**0.000**
FLWG	**0.145**	**0.032**
SRWG	**0.654**	**0.025**
Highest value	**MHMM**	**NHTC**
Lowest value	**PEK**	**CCB, CEC, BJC, PEK, KSK, SJS, LRW, BLWG**

Table 7.2: Reporting Intensities for all odours and landfill odours for each monitor

Male monitor code and Reporting Intensities		Female monitor and Reporting Intensities	
All odours	Landfill odours	All odours	Landfill odours
MKC - 0.132	0.024	CCB - 0.067	0.000
TSK - 0.203	0.081	VHB - 0.427	0.085
DKL - 0.314	0.035	CEC - 0.150	0.000
CBS - 0.256	0.046	NHTC- 0.758	0.209
KBS - 0.397	0.169	BJC - 0.297	0.000
PCW - 0.360	0.058	PEK - 0.000	0.000
JSW - 0.121	0.010	PFK - 0.411	0.033
SRWG - 0.654	0.025	MHK - 0.289	0.066
		KSK - 0.118	0.000
		IKFKH 0.472	0.033
		CMKH 0.532	0.013
		SWKH 0.666	0.016
		NCL - 0.241	0.024
		CJL - 0.047	0.023
		MHMM 0.909	0.182
		CFS - 0.687	0.016
		SJS - 0.036	0.000
		SWS - 0.890	0.121
		LRW - 0.200	0.000
		ERW - 0.122	0.024
		BLWG 0.130	0.000
		FLWG 0.145	0.032
Range of values: All odours: 0.121 to 0.654 Landfill odours: 0.010 to 0.169		Range of values: All odours: 0.0 to0.909 Landfill odours: 0.0 to 0.209	
Highest: all odours = SRWG Highest: landfill odours = KBS		Highest: all odours = MHMM Highest: landfill odours = NHTC	
Lowest: all odours = JSW Lowest: landfill odours = JSW		Lowest: all odours = PEK Lowest: landfill odours = CCB, CEC, BJC, PEK, KSK, SJS, LRW, BLWG	

Table 7.3: Reporting Intensities for male and female monitors

Monitor	Monitor reference and attributes
Female-highest all odours intensity value	**MHMM-56+, EI, no health problems, smoker, new monitor, lived in Vale 3yrs**
Female-lowest all intensity value	**PEK-36-45, Part-time, hay-fever, non-smoker, long-term, lived in Vale 15 yrs**
Female-highest landfill intensity value	**NHTC-18-35,EI, no health problems, non-smoker, new monitor, lived in Vale 32 yrs**
Female-lowest landfill intensity value	**CCB, CEC, BJC, PEK, KSK, SJS, LRW, BLWG-diverse group only features in common are females, no smokers**
Male-highest all odours intensity value	**SRWG-36-45, Full-time, no health problems, passive smoker, new monitor, lived in Vale 2.5yrs**
Male-lowest all odours intensity value	**JSW-46-55, EI, hay-fever, non-smoker, long-term, lived in Vale 50yrs**
Male-highest landfill intensity value	**KBS-56+, EI, no health problems, smoker, long-term, lived in Vale 26yrs**
Male-lowest landfill intensity value	**JSW-as above**

Table 7.4: Monitors producing highest and lowest reporting intensity values for all odour reports and landfill odours

7.2.3 Individual monitors and age

In 2.2.2, the effects of age on olfactory ability were discussed. It was stated that olfactory ability starts to decline around 60 years of age before declining markedly over the age of 70. There were no monitors in the panel who were over 70 years of age in the panel. The results in Section 7.3 revealed the youngest and the older monitors generally produced higher reporting intensities for all odours and landfill odours than other groups (see Table 7.5).

The range of the younger monitors' reports was the largest, varying between 0.0 for monitor SJS and BLWG to 0.209 for monitor NHTC (the highest value produced overall). The 36 to 45 year old group produced the smallest range as well as the lowest values. Five monitors out of this group produced landfill reporting intensities of 0.0. None of the other groups produced so many 0.0 intensity values. This low level of variability suggests that members of this group were perhaps affected by attributes, such as smoking habits or employment patterns to a similar extent. It is notable that there were no smokers in the group, only one monitor was affected by health problems, none of the monitors belonged to the economically inactive group and there was only one male in the group. These factors were identified in Section 7.3 as influencing reporting intensities.

18 to 35 years	36 to 45 years	46 to 55 years	56 years and over
VHB - 0.085	CCB - 0.000	PFK - 0.033	MKC - 0.024
NHTC - 0.209	CEC - 0.000	TSK - 0.081	MHMM - 0.182
SWKH - 0.016	BJC - 0.000	MHK – 0.066	KBS - 0.169
NCL – 0.024	PEK – 0.000	IKFKH - 0.033	PCW - 0.058
CBS – 0.046	KSK - 0.000	CMKH - 0.013	
SJS – 0.000	CFS - 0.016	CJL - 0.023	
SWS – 0.121	SRWG - 0.025	DKL - 0.035	
BLWG – 0.000		ERW - 0.024	
		LRW - 0.000	
		JSW - 0.011	
		FLWG - 0.032	
Range of values 0.0 to 0.209	**Range of values 0.0 to 0.025**	**Range of values 0.0 to 0.081**	**Range of values 0.024 to 0.182**
Highest: NHTC	**SRWG**	**TSK**	**MKC**
Lowest: SJS, BLWG	**CCB, CEC, BJC, KSK, PEK**	**LRW**	**MHMM**

Table 7.5: Landfill reporting intensities for different age groups

7.2.4 Individual monitors and the effects of health problems

Monitors reporting health problems that could affect their olfactory ability produced lower intensity values than those who did not. There was a smaller range of reporting intensity values found in the group of monitors with health problems. This may have arisen due to the number of such monitors being so small or perhaps to health problems being a major influence on reporting intensity (see 2.2.3). The monitor with the highest reporting intensity in this group, MHK, stated that she suffered with asthma, whereas the other three monitors reported suffering from hay-fever and allergies. This may explain why MHK's reporting intensity was higher, as her sense of smell may not have been so adversely affected as the other monitors in the group with health problems.

Amongst the monitors who reported health problems, there was one attribute in common; namely they were all non-smokers. There were three women and one man; they were of different ages, employment pattern, length of time living in the Marston Vale and different length service in the monitor panel. The monitors without health problems produced a wide range of intensity values, from 0.0 (6 monitors produced this value) to 0.209. Only six monitors in this group produced reporting intensities greater than MHK, which may suggest that her asthma did not affect her ability to detect odours and her performance was comparable to other healthy monitors. These monitors were VHB, NHTC, TSK, MHMM, KBS and SWS. They were a diverse group with no other attribute, such as age, gender or same employment pattern, in common.

There are a number of factors to be considered from this information. Firstly, there may be monitors who, despite problems with their health, may be as sensitive to odours as others without problems. Conversely, there may be other monitors who do have impaired olfactory ability and their inclusion in a monitor panel must be considered carefully in the context of why the panel is introduced.

Monitors - reported health problems	Monitors - no reported health problems
BJC - 0.000	**CCB - 0.000**
PEK - 0.000	**VHB - 0.085**
MHK - 0.066	**CEC - 0.000**
JSW - 0.011	**NHTC - 0.209**
	MKC - 0.024
	PFK - 0.033
	KSK - 0.000
	TSK - 0.081
	IKFKH- 0.033
	CMKH- 0.013
	SWKH- 0.016
	NCL - 0.024
	CJL - 0.023
	DKL - 0.035
	MHMM- 0.182
	CBS - 0.046
	KBS - 0.169
	CFS - 0.016
	SJS - 0.000
	SWS - 0.121
	PCW - 0.058
	LRW - 0.000
	ERW - 0.024
	BLWG - 0.000
	FLWG - 0.032
	SRWG - 0.025
Range of values 0.0 to 0.066	**Range of values 0.0 to 0.209**
Highest:MHK	**NHTC**
Lowest:BJC, PEK	**CCB, CEC, KSK, SJS, LRW, BLWG**

Table 7.6: Landfill odour reporting intensities of monitors with and without health problems

If, as in the case of this research, an effort is being made to identify the extent of odour impact on the general community, then individuals with health problems should be included, as they will be found in the community. Their inability to detect odours as frequently as other monitors would be identified and "allowed for" when examining their patterns of reports.

7.2.5 Individual monitors and smoking

Smokers produced high reporting intensity values, as discussed in Section 7.3. There was a wide range of intensities found in this group, from 0.013 to 0.182. This was surprising when considering that research suggested that smokers could have impaired olfactory ability (see 2.2.5). It should be noted that individual non-smokers did produce higher reporting intensity values than individual smokers, the highest value reported by a non-smoker being 0.209.

Smokers	Passive exposure	Former smokers	Non-smokers
CMKH - 0.013	**CCB - 0.000**	**MHK - 0.066**	**CEC - 0.000**
MHMM - 0.182	**VHB - 0.085**	**KSK - 0.000**	**NHTC- 0.209**
KBS - 0.169	**SWKH- 0.016**	**DKL - 0.035**	**BJC - 0.000**
	CBS - 0.046	**CFS - 0.016**	**MKC - 0.024**
	ERW - 0.024	**BLWG - 0.000**	**PEK - 0.000**
	SWS - 0.121	**SRWG - 0.025**	**PFK - 0.033**
			TSK - 0.081
			IKFKH- 0.033
			NCL - 0.024
			CJL - 0.023
			SJS - 0.000
			PCW - 0.058
			LRW - 0.000
			JSW - 0.011
			FLWG - 0.032
Range of values 0.013 to 0.182	**Range of values 0.0 to 0.121**	**Range of values 0.0 to 0.066**	**Range of values 0.0 to 0.209**
Highest: MHMM	**SWS**	**MHK**	**NHTC**
Lowest:CMKH	**CCB**	**KSK, BLWG**	**CEC, BJC, PEK, SJS, LRW**

Table 7.7: Reporting Intensities based on exposure to cigarette smoking

The group with the widest range of intensities was the non-smokers group. However, apart from one high value reporting intensity, 0.209 (NHTC), other values were as low as others seen in other groups. Monitor NHTC was female, in the 18-35 age group, had no health problems and was a new monitor. In fact two of the smokers' intensity values were similarly high, 0.182 (MHMM) and 0.169 (KBS). They were both 56+, had no health problems and were economically inactive.

This contradicts some of the literature which states smokers have impaired abilities to detect and identify odours. In laboratory trials olfactory testing involves the use of individual compounds. Therefore comparisons between the two types of data may be difficult as, as described in Section 3.3 odours usually consist of "cocktails" of odour-causing compounds.

7.2.6 Individual monitors and employment category

The pattern of response seen in different employment categories also varied, with economically inactive individuals producing the highest intensity value, 0.209. This group also produced the widest range of reporting intensity values amongst the employment groups.

Full-time workers	Part-time workers	Economically Inactive
MKC - 0.024	**CCB - 0.000**	**VHB - 0.085**
MHK - 0.066	**CEC - 0.000**	**NHTC - 0.209**
KSK - 0.000	**BJC - 0.000**	**CJL - 0.023**
TSK - 0.081	**PEK - 0.000**	**MHMM - 0.182**
IKFKH - 0.033	**PFK 0.033**	**KBS - 0.169**
CMKH - 0.013	**SJS - 0.000**	**PCW - 0.058**
SWKH - 0.016	**ERW - 0.024**	**JSW - 0.011**
NCL - 0.024	**BLWG - 0.000**	**FLWG - 0.032**
DKL - 0.035		
CBS - 0.046		
CFS - 0.016		
SWS - 0.121		
LRW - 0.000		
SRWG - 0.025		
Range of values 0.0 to 0.121	Range of values 0.0 to 0.033	Range of values 0.011 to 0.209
Highest: SWS	PFK	NHTC
Lowest: KSK, LRW	CCB, CEC, BJC, PEK, SJS, BLWG	JSW

Table 7.8: Reporting Intensities based on employment group

The high values produced would not be surprising as they would have the longest potential exposure time compared to other employment groups. The full-time workers produced the second widest range of values along with high individual reporting intensities. Monitor SWS produced a high reporting intensity value of 0.121. This is a surprise as it is much greater than other values in this group, the next nearest value being 0.081 (TSK). It is known however, that she worked from home as a child-minder, and therefore, like the economically inactive group, would be at home a great deal.

It would be anticipated that part-time workers would produce higher intensities than full-time workers, due to the greater chance of their being at home and having longer potential exposure times. This was not the case. This group produced the highest number of zero intensity values, six in all (monitors CCB, CEC, BJC, PEK, SJS and BLWG). Examination of their other attributes showed that two of this group had health problems (BJC and PEK). Additionally, all but one monitor at Stewartby (SJS) lived at locations that were not as adversely affected by landfill odours. Additionally, six of them were in age groups that produced lower reporting intensities. These factors could have influenced the levels of their exposure and response.

7.2.7 Individual monitors at settlements across the Marston Vale

It was also decided to examine landfill odour reporting intensities for monitors at each settlement. These are shown in Table 7.9.

Brogb'	Cran'	Kemp'	Kemp Hk	Lidling	Mar.M	Stewar	Woot'	Woot Gr
0.0	0.0	0.0	0.033	0.024	0.182	0.046	0.058	0.0
0.085	0.209	0.033	0.013	0.023		0.169	0.0	0.032
	0.0	0.066	0.016	0.035		0.016	0.024	0.025
	0.024	0.0				0.0	0.011	
		0.081				0.121		
Range 0.0 to 0.085	**Range 0.0 to 0.209**	**Range 0.0 to 0.081**	**Range 0.013 to 0.033**	**Range 0.023 to 0.035**	**One value 0.182**	**Range 0.0 to 0.169**	**Range 0.0 to 0.058**	**Range 0.0 to 0.032**

Table 7.9: Landfill odour reporting intensities at each settlement

It can be seen from the table that the settlements with the highest reporting intensity values are Cranfield, Stewartby and Marston Moretaine. These areas have been identified as settlements with high intensity values (see Section 8.2). It is probable that proximity to the landfill sites is an influential factor in this pattern. Individual monitors at Brogborough, Cranfield, Kempston, Stewartby, Wootton and Wootton Green reported values of zero. The settlements with the largest range of intensity values are Cranfield and Stewartby. These were settlements with 4 and 5 monitors respectively, and therefore, potentially, settlements where such a range may occur. However, as Cranfield and Stewartby were identified as potential blackspots, it is interesting that individual monitors such produce very high and zero intensity values. The two monitors at each settlement producing the highest values were both economically inactive and may have been at home more frequently and therefore more likely to be exposed to odour. In fact they were the only economically inactive monitors at each of these settlements. However, apart from that attribute, they differ markedly. The monitor at Cranfield, NHTC, being female, aged 18 to 35, non-smoker and a new monitor. The monitor at Stewartby, KBS, being male aged 56+, a smoker and long-term monitor.

The other monitors at these two settlements were a diverse group. At Cranfield, two of the other monitors, CEC and BJC were both part-time workers, a group with a low reporting intensity pattern. CEC was also a long-term monitor, a group with a lower intensity pattern. SJS, the one monitor at Stewartby producing the only zero intensity value was a long-term monitor who worked part-time. The settlements with the smallest range of values were Kempston Hardwick and Lidlington. At Kempston Hardwick, the monitors had certain attributes in common. They were all female, all full time workers and all new monitors. Therefore it is not perhaps surprising that their intensity values were very similar, ranging from 0.013 to 0.033. At Lidlington, the monitors were a more diverse group. There were two females and a male, one long-term monitor and two new monitors, two 46 to 55 year olds and one 18 to 35 year old, and two full-time workers and one economically inactive monitor. It is notable that the male monitor produced the highest intensity value, the female values were almost the same (0.023 and 0.024).

7.3 Attributes of the individual and their influence on odour perception

In this section, the differing attributes of monitors and their influence on exposure to odours are examined. The attributes include physiological attributes (gender, age, health), lifestyle (cigarette smoking, working patterns) and psychological attributes (opinion of and length of time spent living in the Marston Vale). As referred to in Section 7.1, these attributes were identified from the literature review and from the results of the pilot study panel as influencing exposure and response to odour.

In each sub-section, the results of χ^2 tests carried out on the numbers of reports made by attribute groups are also presented. These tests were undertaken to identify any significant differences in the report rates and intensity between different groups of monitors. It should be stressed that in order to calculate the χ^2 values for the tests below, the number of reports made were used, not the reporting intensity values. The reporting intensity values, however, were used in the population framework developed in Chapter 10.

7.3.1 Effects of gender

Gender was identified in Section 2.2 as an attribute that may affect odour perception and it was noted in the pilot study that gender might have affected reporting patterns. Therefore it was identified as being located in the physiological component in Section 4.2 and included in research objective 2 related to the influence physiological attributes could have on reporting patterns. The reports made by male and female monitors were analysed for any similarities and differences in the reporting pattern. There were 22 female monitors and 8 male monitors. There were no male monitors at Brogborough, Kempston Hardback or Marston Moretaine. The numbers of odour reports recorded are shown below in Table 7.10.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	**Total reports**
Male	**100 (49%)**	**39 (19%)**	**50 (24%)**	**17 (8%)**	**206 (100%)**
Female	**183 (31%)**	**72 (12%)**	**265 (45%)**	**70 (12%)**	**590 (100%)**

Table 7.10: Breakdown of reports by male and female monitors

The numbers of reports are also displayed graphically in Figure 7.3.
It can be seen that the most frequently reported odour by male monitors was that of local odours (49% of reports). Female monitors reported brickwork odours most frequently (45%). Landfill odour was the third most frequently reported odour by both males and females.

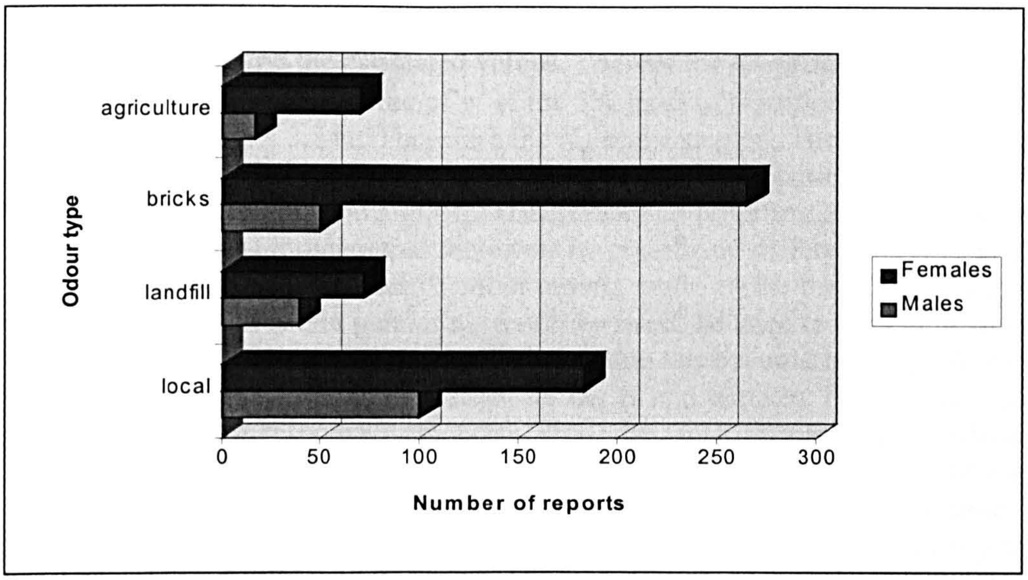


Figure 7.3: Breakdown of reports made by male and female monitors

	Number of monitoring days	All odour intensity value	Landfill odour intensity value
Male	**670**	**0.307**	**0.058**
Female	**1758**	**0.336**	**0.041**

Table 7.11: Reporting intensity values for male and female monitors

The intensity values of all odours and landfill odour were calculated for reports by males and females. These are shown in Table 7.11. As can be seen from the table, female monitors have a slightly higher intensity value for all odour types, whilst male monitors have a higher intensity value for landfill odour.

In order to identify if the differences observed in reporting patterns between males and females were significant, χ^2 tests were carried out using the number of reports made by each group recorded in Table 7.11 (not reporting intensity values). These tests involve calculating if there are significant differences between the observed number of reports and hypothetical or expected results. The calculations for "all odour" reports were as follows,

	Observed	Expected
Females	590	581
Males	206	215

$$\chi^2 = \frac{(590-581)^2}{581} + \frac{(206-215)^2}{215}$$

$$\chi^2 = 0.14 + 0.38$$
$$\chi^2 = 0.52$$

The null hypothesis (H_0) stated that there would be no significant difference in reporting patterns and the estimated values. The test for all odour types produced a χ^2 value of 0.52. The critical value of χ^2 at the 5% level of significance and with 1 degree of freedom, is 3.841. Therefore the H_0 was accepted. The test for landfill odour, calculated as above, produced a value of 3.7. As the critical value is 3.841, again the H_0, that there is no significant difference in reporting levels is accepted. The results of these tests indicate that there was no significant difference between the number of "all odour" and landfill odour reports made on the basis of gender. A working conclusion is that gender need not, by itself, be used to discriminate response to odour. It was anticipated from the literature that there would be a significant difference between reporting intensities for males and females. For the purpose of development of the response framework, it will be assumed that there is a difference in ability to discriminate odours on the basis of gender. However this result may indicate that gender may not be as critical a factor in olfactory ability as some research suggests. In 2.2.4, reports suggested that gender did affect olfactory ability, but differed in suggestions of what the effects were. This variability in response together with the results observed in this research suggests that further research into gender and olfactory ability should be carried out to clarify if there are effects and what they are (see Section 11.4).

7.3.2 Effects of monitor age

Like gender, the age of monitors was identified as potentially influencing reporting patterns in the pilot panel study. Therefore, like gender, it is also included in the physiological component and is located in research objective 2. Volunteers taking part in the second, re-designed panel were asked to state to which age group they belonged on the pre-monitoring questionnaire (Question 5 see 6.4.2). The data from monitors were divided into the age groups outlined in Section 6.5. The numbers of monitors in each group were eight 18 to 35s, seven 36 to 45s, eleven 46-55s and four over 56 year olds respectively. The breakdown of the reports by each group is shown in Table 7.12 and in Figure 7.4.

Age group (years)	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total
18 to 35	**101**	**43**	**118**	**14**	**276**
36 to 45	**89**	**3**	**25**	**24**	**141**
46 to 55	**64**	**26**	**122**	**12**	**224**
56+	**29**	**39**	**50**	**37**	**155**

Table 7.12: Breakdown of odour reports by age group

The youngest age category produced the largest percentage of reports (34.6%). The lowest number of reports was made by the 36 to 45 years age group (17.7%). This was despite the two groups having a similar number of monitors.

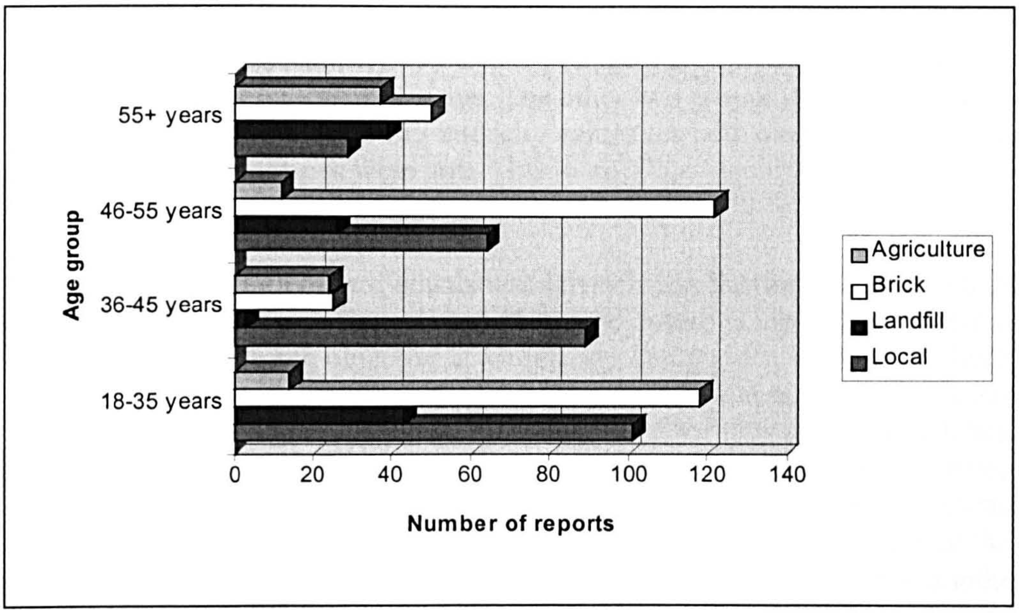


Figure 7.4: Breakdown of reports by age group

χ^2 tests were carried out to identify if there were significant differences between observed and expected reporting levels for the different age groups. The reporting totals shown in Table 7.12 were used.

- The critical value of χ^2 at the 5% level of significance with 3 degrees of freedom is 7.812.
- The H_o states that there is no significant difference between the observed and expected number of reports.
- The calculated χ^2 value for all odour reports is 69.8, which means the H_o is rejected.
- Similarly, the calculated χ^2 value for landfill odours is 51.6, meaning that the H_o is again rejected.

This means that, as there is a significant difference between the observed and expected values, age would appear to be a significant factor in influencing response to odours.

The reporting intensity values were calculated for each age group for all odours and landfill odour. These are shown below in Table 7.13,

Age group	Reporting days	Number of reports	All odour intensity	Landfill odour intensity
18 to 35	**655**	**276**	**0.42**	**0.07**
36 to 45	**539**	**141**	**0.26**	**0.005**
46-55	**894**	**224**	**0.25**	**0.03**
56+	**340**	**155**	**0.46**	**0.11**

Table 7.13: Reporting intensities for the different age groups

The reporting intensities show that the oldest age group, the 56 years plus group has the highest reporting intensity value. The youngest group, the 18 to 35 produced the next highest reporting intensity value. The other two groups, the 36 to 45 and the 46 to 55 have very similar reporting intensity values for both overall odour, but landfill odour reporting intensities were not.

7.3.3 Effects of health

The state of the health of individuals was identified in Section 2.2 as affecting olfactory ability. Like gender and age, therefore, health is located in the physiological component and research objective 2. Unlike age and gender, whether the health of monitors influenced reporting patterns in the data from the pilot panel is unknown. The monitors for the pilot panel had not stated whether they suffered with health problems. Therefore a question relating to health was included on the questionnaire completed by volunteers joined the redesigned panel developed for this research (Question number 6 - see 6.4.2). There were four monitors who stated that they had health problems that may affect their sense of smell. One had allergies, another had asthma and two stated that they suffered from hayfever. The numbers of reports between the group of monitors with health problems and those without were compared as above. The breakdown of the reports is shown in Table 7.14.

Health group	Local odours	Landfill odours	Brickwork odours	Agricultural odours	Total
No health problems	**259**	**107**	**298**	**75**	**739**
Health problems	**24**	**4**	**17**	**12**	**57**

Table 7.14: Breakdown of reports on the basis of health problems, which may affect the sense of smell

Statistical testing suggested that there was a significant difference in reporting levels between the two groups, both with overall odour reports. Testing for the significance level of landfill odour reports could not be carried out as there were less than 5 reports in the monitors with health problems category.

- The H_0 stated that there would be no difference between the observed and expected values.
- The critical value of χ^2 with 1 degree of freedom at 5% significance is 3.841.
- The χ^2 value calculated for all odour reports was 23.7. The H_0, is rejected.

Care must be taken when examining the results from the health problem group, as it is very small, consisting only of four individuals. This is despite grouping all the monitors together and despite the differences there may be in their medical conditions.

These data are also displayed graphically in Figure 7.5 below.

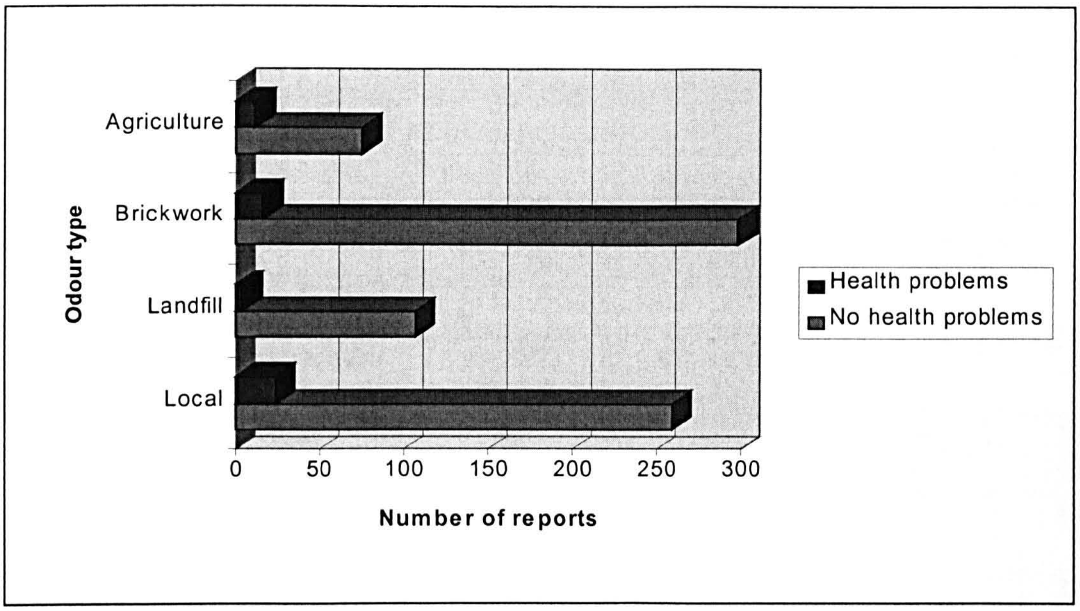


Figure 7.5: Breakdown of reports by monitors with or without health problems which may affect the sense of smell

The reporting intensities were calculated for the two groups are shown in Table 7.15.

Health Group	Reporting days	Total reports	reporting intensity	Landfill reports	Landfill intensity
No health problems	**2102**	**739**	**0.35**	**107**	**0.05**
Health problems	**326**	**57**	**0.17**	**4**	**0.01**

Table 7.15: Reporting intensities for monitors with and without health problems that may affect the sense of smell

The reporting intensities for both groups were markedly different for both odour groups. The healthy group had higher intensity values for both odour types, meaning they have a higher level of exposure to odour than the group with health problems. Therefore, the group that suggested they may have problems with their sense of smell is less likely to detect all the odours they are exposed to unlike their neighbours with no such problem.

7.3.4 Effects of cigarette smoking

In Section 2.2, cigarette smoking was cited as a behaviour that may affect olfactory ability. Unlike the physiological attributes, such as age or gender, it is located in the lifestyle component and therefore relates to research objective 2. This question asked if factors relating to lifestyle would influence exposure and response to odour. In the pilot study, monitors were not asked about their smoking habits and exposure to cigarette smoke and therefore it was unknown if this was a factor affecting the reporting patterns of monitors. Questions on smoking were included in the pre-monitoring questionnaire (Questions 1 to 4 - see 6.4.2). The monitors were asked if they smoked, had smoked in the past or were exposed to cigarette smoke at home or at work. The monitors were divided into several groups as follows. These were smokers, non-smokers, former smokers and passive smokers (people exposed to smoking at home or at work). There were 3 smokers, 15 non-smokers, 6 former smokers and 6 passive smokers. The breakdown of the reports they made is shown below in Table 7.16. The data are also displayed graphically in Figure 7.6. The reporting intensities were calculated for each group and are shown in Table 7.17.

	Local odours	Landfill odours	Brickwork odour	Agricultural odour	Total
Smoker	**22**	**31**	**69**	**24**	**146**
Non smoker	**95**	**45**	**102**	**39**	**281**
Former smoker	**66**	**9**	**32**	**18**	**125**
Passive smoker	**100**	**26**	**112**	**6**	**244**

Table 7.16: Breakdown of reports by smokers, non-smokers, former smokers and passive smokers

Statistical tests for significance between the reporting patterns of the different groups for all odours and landfill odour were carried out.

- The H_0 stated that there would be no difference between the observed and expected number of reports.
- The critical value for χ^2 with 3 degrees of freedom at 5% significance is 7.81.
- The χ^2 value for all odour reports was 141.9 and 47.3 for landfill odour.
- The H_0 was rejected.

It can be seen that the reporting intensities for smokers and passive smokers are highest for both overall odours and landfill odours. This is surprising considering there are some references in the literature to individuals having reduced sensitivity to odour if they smoke. However it should be noted that the smoking group consisted only of three people, all of whom lived in areas strongly associated with odour impact, namely Kempston Hardwick, Marston Moretaine and Stewartby. It may be possible that other factors affecting exposure were also operating in this group. For example on of the monitors fell into the economically inactive group, another into the part-time working group. Both of these groups produced higher reporting intensity values. The group being so small was undesirable and more smokers in the panel would have been useful, particularly if they lived in other parts of the Vale.

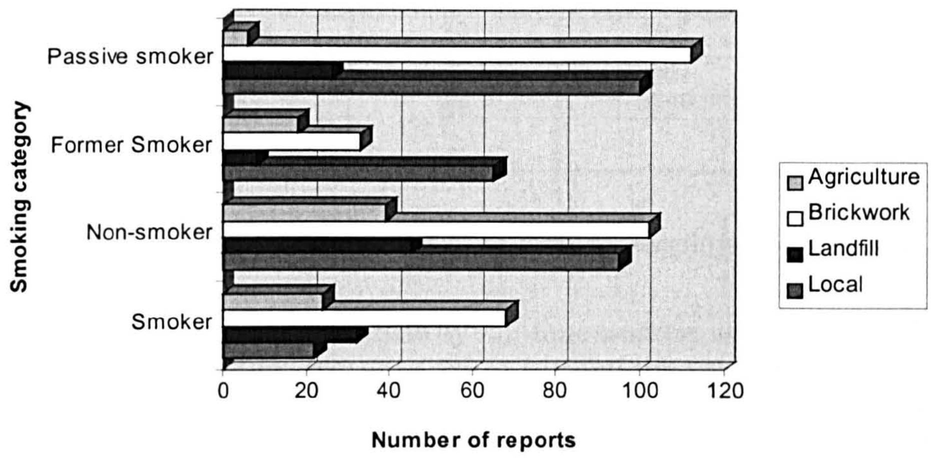


Figure 7.6: Breakdown of reports by different smoking or non-smoking categories

	Reporting days	total reports	total reporting intensity	landfill odour reports	landfill odour intensity
Smokers	**248**	**146**	**0.59**	**31**	**0.13**
Non-smokers	**1152**	**281**	**0.24**	**45**	**0.04**
Passive smokers	**483**	**244**	**0.5**	**26**	**0.05**
Former smokers	**545**	**125**	**0.23**	**9**	**0.02**

Table 7.17: Reporting intensities for different smoking or non-smoking groups

7.3.5. Effects of working patterns

The results from the data analysis from the pilot study revealed peak times for odour reports, at 8am, 3pm and 7pm. In Section 5.2, it was proposed that such patterns may emerge due to working patterns, an attribute associated with lifestyle that is when individuals leave or return home. In order to find out if this was the case, monitors were asked in the pre-monitoring questionnaire what their working patterns were (Question 7 - see 6.4.2). The monitors were divided into three groups. These were full-time workers (14 monitors), part-time workers (8 monitors) and the economically inactive, namely housewives, carers and retired people (8 monitors). The breakdown of their reports is shown in Table 7.18. These data are also displayed graphically below in Figure 7.7.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total
Full-time	**164**	**39**	**202**	**24**	**429**
Part-time	**38**	**5**	**40**	**19**	**102**
Economically Inactive	**81**	**67**	**73**	**44**	**265**

Table 7.18: Breakdown of reports by employment pattern

The largest category of reports made by full-time workers was that of brickwork odour (47%). This pattern may arise due to four full-time workers producing high levels of brickwork odour reports as they lived in close proximity to brickwork sites at Kempston Hardwick and Stewartby. Brickwork odour was the largest category produced by part-time workers (40%) and local odours were most frequently reported by the economically inactive category (30%).

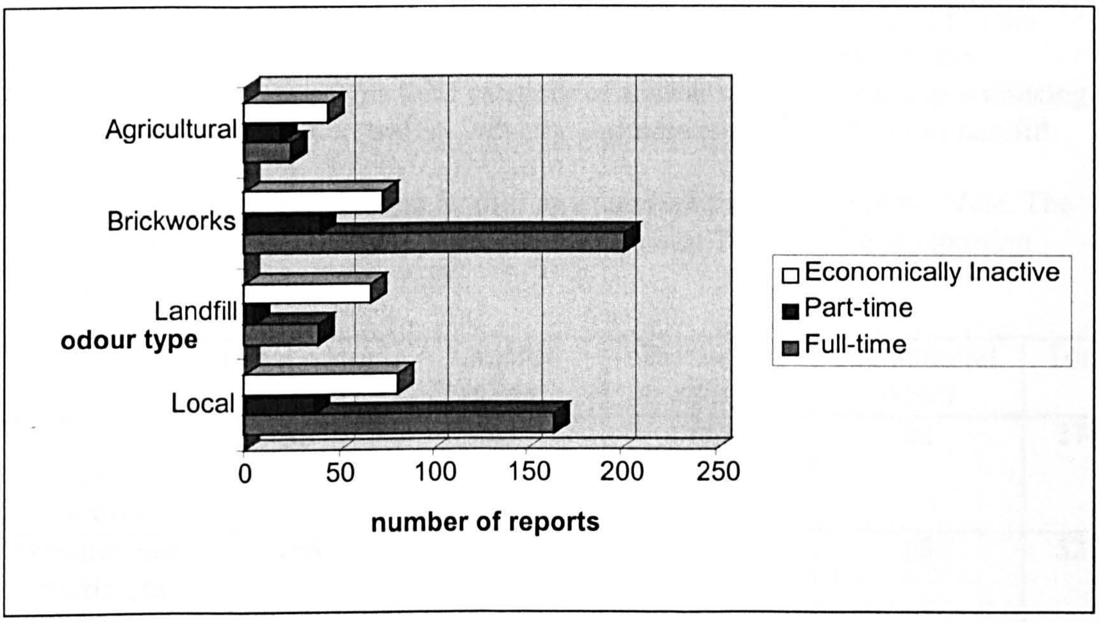


Figure 7.7: Breakdown of reports by employment category

The reporting intensities are shown below in Table 7.19.

	Reporting days	Total odour reports	Reporting intensity	Landfill reports	Landfill intensity
Full-time	**1052**	**428**	**0.41**	**39**	**0.04**
Part-time	**719**	**102**	**0.14**	**5**	**0.007**
Economic. Inactive	**657**	**266**	**0.40**	**67**	**0.10**

Table 7.19: Reporting intensities for different employment groups

Statistical testing revealed that there were significant differences between reporting levels between the different groups for all odours and landfill odour.

- The critical value of χ^2 with 2 degrees of freedom at 5% significance is 5.99.
- The calculated value for all odours was 79.45 and 72.95 for landfill odour.
- The H_0, that there was no significant difference in observed and expected reports, is rejected.

The economically inactive group produced the highest reporting intensity for landfill odours. Full-time workers produced a slightly higher value for overall odours. This is surprising as it would be expected that they are away from home for longer periods during the day and therefore be less likely to experience odours.

7.3.6 Effects of opinion of the Marston Vale

Response to odour is recognised as being not only a physiological process, but also a psychological one. In order to identify if reporting patterns may be influenced by the individual's opinion of the odour source or their locale, monitors were asked to state three things they liked and disliked about their local area (Questions 13 and 14 - see 6.4.2). Three types of answer were examined. Firstly, if monitors referred to the landfill, secondly, if they referred to odour or thirdly, if they referred to the environment in any way. This third category of answer was a large group consisting of answers relating to litter, traffic, industry, lighting as well as odours or landfill.

Thirteen monitors referred to the landfill as an undesirable feature of the Vale. The patterns of reports for both groups are shown below in Table 7.20 and reporting intensities are shown in Table 7.21.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total
Monitors referring to Landfill	**98**	**41**	**113**	**22**	**274**
Monitors not referring to Landfill	**185**	**70**	**202**	**65**	**522**

Table 7.20: Reporting pattern of monitors referring to landfill as detrimental to their local environment

For both groups of monitors, brickwork odour was most commonly reported. The percentage of the reports was around 40% for each group. Landfill odour was the third most common category of odour reported. Again the percentages were similar, being 15% of reports by monitors who referred to landfill and 13.5% by those who did not.

- The critical value of χ^2 at 5% significance with 1 degree of freedom is 3.841.
- The H_0 for both tests was there is no significant difference between observed and expected report numbers.

- The χ^2 value calculated for "all reports" made by monitors referring to landfill was 21.0. This means that there is a significant difference between the two groups.
- The χ^2 value calculated for landfill odour reports was 1.80. The H_o, that there is no significant difference between reporting levels of both groups is accepted.

As can be seen from Table 7.21, the reporting intensity of monitors who referred to the landfill is lower than those who did not. Therefore it appears that disliking the landfill does not appear to influence the rate of reporting landfill odour, but results in greater sensitivity to odour generally.

	Reporting days	Total reports	Reporting intensity	Landfill reports	Landfill intensity
Monitors referring to landfill	**1045**	**274**	**0.26**	**41**	**0.04**
Monitors not referring to landfill	**1383**	**522**	**0.38**	**70**	**0.05**

Table 7.21: Reporting intensities based on attitude to landfill

The next category examined the reporting intensities of monitors who referred to odours as something they disliked about the Vale. Seven monitors made specific reference to odour as being detrimental to the area. The breakdown of reports is shown in Table 7.22 and the reporting intensities of the two groups are shown in Table 7.23.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total reports
Monitors referring to odour	**38**	**27**	**121**	**8**	**194**
Monitors not referring to odour	**245**	**84**	**194**	**79**	**602**

Table 7.22: Reporting pattern of monitors referring to odour as detrimental to the environment

The largest number of reports by monitors who referred to odour is in the brickwork category; the monitors not referring to odour produced more reports in the local odour category. Landfill odour was again the third largest category. All but one of the group of monitors who referred to odour as being detrimental to their environment lived in settlements with high levels of odour reports. These were Kempston Hardwick, Stewartby and Kempston. Therefore it is not surprising perhaps that these monitors considered odour to be of some importance. The one other monitor in this group lived in Wootton.

	Reporting days	Total reports	Reporting intensity	Landfill reports	Landfill intensity
Monitors referring to odour	**586**	**194**	**0.33**	**27**	**0.05**
Monitors not referring to odour	**1842**	**602**	**0.33**	**84**	**0.05**

Table 7.23: Reporting intensities based on attitude to environmental odours

When the reporting intensities are examined, the values are the same between the two groups. Statistical results indicated a similar pattern.

- The critical value of χ^2 at 5% significance with 1 degree of freedom is 3.841.
- The χ^2 value calculated for all odours was 0.9 and 0.17 for landfill odour.
- This indicates that there was no significant difference between reporting patterns of monitors referring to odour for all odours and landfill odour.

Therefore it could be argued that a monitor having a dislike of odour in the environment would not necessarily affect reporting behaviour.

The final category examined was that of monitors referring to features in the general environment that they did not like. Twenty-five monitors fell into this category. The breakdown of reports of the two categories is shown in Table 7.24 and their reporting intensities are shown in Table 7.25.

The largest odour category amongst people expressing dissatisfaction with their environment was that of brickwork odour (44%). This group consisted of monitors from every settlement in the Vale. The other group produced higher levels of local odour reports (54%). They were reporting from Kempston (3 monitors), Cranfield (2 monitors) and Lidlington (1 monitor). This was interesting as, certainly, Cranfield is a location with a higher level of reports than most settlements.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total reports
Monitors referring to envirnmt	**221**	**84**	**300**	**77**	**682**
Monitors not referring to envirnmt	**62**	**27**	**15**	**10**	**114**

Table 7.24: Breakdown of reports of monitors referring to dissatisfaction with the environment

	Reporting days	Total reports	Reporting intensity	Landfill reports	Landfill intensity
Monitors referring to envirnmt	**2004**	**682**	**0.34**	**84**	**0.04**
Monitors not referring to envirnmt	**424**	**114**	**0.27**	**27**	**0.06**

Table 7.25: Reporting intensities based on attitude to the environment

Whilst monitors who referred to the environment produced a higher reporting intensity than those who did not, landfill reporting intensity was highest amongst monitors not referring to the environment. Statistical testing of the reporting patterns was undertaken.

- The critical value of χ^2 at 5% significance with 1 degree of freedom is 3.841.
- The H_0 was rejected and there was no significant difference in reporting levels.
- The χ^2 value calculated for all odour reports was 3.3.
- A value of 4.06 was calculated for landfill odour reports, meaning that there was a significant difference in reporting levels between the two groups.

It would appear that awareness of the general environment results in individuals making higher levels of landfill odour reports.

7.3.7 Effect of length of time monitoring

The discussion in Section 2.3 involved examining how experience and judgment could affect the response to odour pollution as part of an individual's appreciative system. Punter (1987) also described how monitors could suffer from monitoring fatigue and tend to under-report odours as a result. It was decided to identify if reporting patterns differed between long-term monitors, who had monitored for the pilot study and who wished to continue monitoring, and new monitors who had joined the re-designed panel. There were 10 monitors who had been monitoring before the three months monitoring period and twenty who had started monitoring at that time. The breakdown of the reports is shown in Table 7.26 and reporting intensities of the two groups are shown in Table 7.27.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total reports
Long-term monitors	**31**	**25**	**59**	**9**	**124**
Short-term monitors	**252**	**86**	**256**	**78**	**672**

Table 7.26: Breakdown of reports by long-term and short-term monitors

For both groups of monitors, brickwork odour was most frequently reported, followed by local odours. However, the level of reporting was markedly higher for new monitors rather than the long-term monitors. This is illustrated by the reporting intensity values in Table 7.27.

	Reporting days	Total reports	Reporting intensity	Landfill reports	Landfill intensity
Long-term monitors	**792**	**124**	**0.16**	**25**	**0.03**
New monitors	**1636**	**672**	**0.41**	**86**	**0.05**

Table 7.27: Reporting intensities of long-term and new monitors

The reporting intensities of the new monitors for all odours and for landfill odours were higher. Statistical testing for significant differences in reporting levels was undertaken.

- The critical value of χ^2 with 1 degree of freedom at 5% significance is 3.841.
- The calculated value for all odour reports was 100 and for landfill odour, 5.8.
- This resulted in rejection of the H_0 for both tests, meaning that there were significant differences between the two groups.

The difference may arise from loss of motivation with prolonged monitoring or from long-term monitors using their judgment about whether or not to report an odour. Whatever the cause, questions are raised about how long monitors should be retained if they do not report all odours. This may have implications for the management of monitoring panels. Use of monitoring panels may involve reviewing reporting patterns of monitors at regular intervals, for example every six months or a year in order to assess if loss of motivation occurs. New monitors should be allowed to settle into the routine of monitoring if they are likely to over report odours. It was noticeable that the numbers of reports made by new monitors did fall slightly during the monitoring period, possibly for the reasons mentioned above.

7.3.8 Effect of length of time living in the Vale

As with the influence of the length of time spent monitoring, it was hoped to identify how the length of time a monitor had lived in the Marston Vale would influence reporting patterns. On the pre-monitoring questionnaire, monitors were asked to state how long they had lived in the area (Question 12 - see 6.4.2). The length of time spent living in the area was seen as contributing to the monitors' experience of the area and their appreciative system. The monitors had lived in the Vale for periods varying between less than 1 year to 50 years. The monitors were split into groups on the basis of the length of time they had been in the Vale. The groupings were up to 5 years (9 monitors), 6 to 10 years (6 monitors), 11 to 20 years (7 monitors) and over 21 years (8 monitors). The reporting intensities of the different groups are shown in Table 7.28.

There is no clear pattern that emerges from the values in Table 7.28. The overall reporting intensity values are highest for the 0-5 year group and are lowest for the 11-20 year group. The values for the 0-5 year and 20+ year groups are similar consistent for landfill odour as are the 6-10 year and 11-20 year groups.

Length of time in Vale	Reporting days	Total reports	Reporting intensity	Landfill reports	Landfill intensity
0-5 years	**764**	**402**	**0.53**	**42**	**0.05**
6-10 years	**419**	**151**	**0.36**	**13**	**0.03**
11-20 years	**590**	**56**	**0.1**	**11**	**0.02**
21+ years	**655**	**187**	**0.28**	**45**	**0.07**

Table 7.28: Reporting intensity values calculated on the basis of length of time lived in the Marston Vale

Statistical tests to identify significant differences in reporting levels were carried out.

- The critical value of χ^2 at 3 degrees of freedom at 5% significance is 7.81.
- The calculated χ^2 value for all odour reports was 202.1 and for landfill odour reports was 21.4.
- The H_0 for both tests was rejected.
- This indicated that there were significant differences between the groups of people living different lengths of time in the Marston Vale.

Whether this occurs through adaption or habituation of exposure to odour, or increased indifference over time is not clear. It would be perhaps not unreasonable for individuals new to an area to be more sensitive to features, such as odour, which long-term residents take for granted. However, when examining aspects of the Marston Vale which were disliked in the questionnaire, the 10 long-term monitors referred to odours five times, the 20 new monitors referred to odours 4 times. This similarity indicates that, in the Marston Vale at least, the local populace may not "get used to" odours. However, the response of individuals may vary as a consequence of the length of time they have lived in a particular area that experiences odour pollution. As with the length of time spent monitoring (see 7.3.7), management of an odour monitoring panel may involve assessment of reporting behaviour who have lived in the area for differing lengths of time. This may involve removing people from the panel if their behaviour is out of step with other monitors due to the length of time they have lived in a particular area.

7.3.9 Effect of lifestyle

Monitors were asked when completing their reports, to state where they were or what they were doing. The results are shown in Figure 7.8.

It will be recalled from Chapter 6, that monitors were instructed to sniff the air at home at a set time, 8.00am, every day. They were also asked to record odours they detected at any other time, either at home or elsewhere. It can be seen from the figure that monitors detected odour most frequently when actively monitoring for odours. It could be argued from this that monitors are most likely to detect odours if they are actively sniffing for them. After the monitoring category, odours were most frequently detected when monitors were driving, in their garden or were outside. It is notable that only a small proportion of the reports (18 or 2% of reports) was made when monitors were indoors. This would suggest that monitors are most likely to detect odours when outside. Therefore individuals who are outside most frequently, for example working out of doors, may be more likely to experience odour nuisance than others who spend more time indoors. This may appear logical at first sight. However, the behaviour of individuals and their being indoors or outdoors is not often taken into account when studies into odour impact are undertaken.

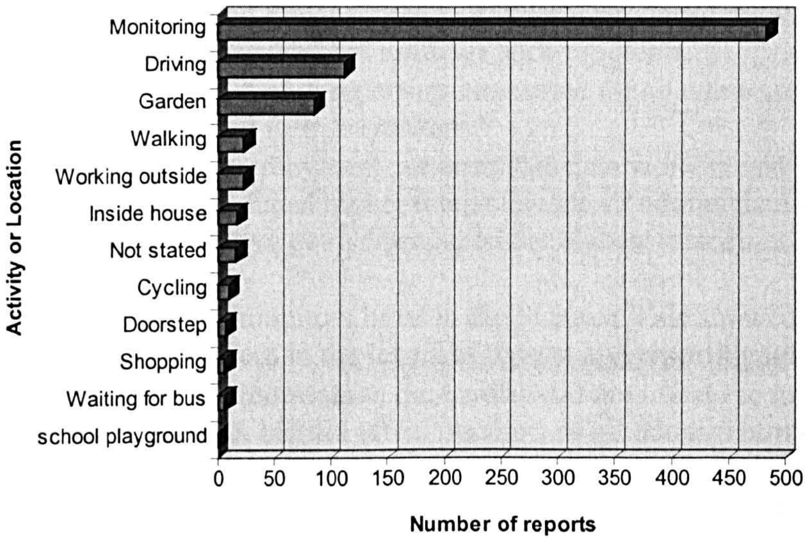


Figure 7.8: Activity or location of monitors at the time of their report

These results have implications both for research design and the wider area of assessment of odour impact on amenity. The use of monitor panels, must take into account the life-style of individuals if the impact of odour is to be fully understood. This would include the amount of time individuals are indoors or outside, when they are at home and for how long. This may entail the use of more detailed reports on the location and activity of monitors, for example, always asking if they are indoors or outside and more details of their activity. Account must be taken of the seasonal effects of lifestyle, for example, is nuisance most likely in the summer, when individuals are more likely to be outside or at least have windows open. Individuals who work outside may be more likely to be exposed, so monitors should be asked for more details about what their jobs entail. Similarly, the effects of seasonality and lifestyle may have to be taken into account in impact on amenity studies

7.4 Summary

The results from the examination of the monitors' reports are summarised below.

- The reports made by individual monitors showed little similarity with other monitors and varied substantially.
- Female monitors reported all odours more frequently, but males reported landfill odour more often. Statistical testing revealed these results were not significant with the sample in this research, but for the purpose of generating the response framework, gender will still be used simply to demonstrate how the framework is developed. It was anticipated from the literature that gender would have influenced

reporting levels. That this was not the case raises the issue of further research into the effects of gender on olfactory ability. If it does not have any affect then gender would be excluded from any potential response framework or future model or given very little weighting.

- The oldest and youngest monitors reported both overall odours and landfill odours more frequently.
- Monitors who stated they had health problems produced markedly fewer reports of all odours than those who did not have such problems.
- Smokers produced higher reporting intensities for all odours than non-smokers, passive smokers and former smokers.
- When examining employment patterns, full-time workers and economically inactive people produced higher intensities for all odours than part-time workers. Economically inactive people produced the highest intensities for landfill odour reports.
- The length of time monitors lived in the Marston Vale showed statistically significant differences in the levels of reports and reporting intensities produced.
- The opinion of the monitors to the landfill did not affect the numbers of landfill odour reports made, but did affect numbers of all odour reports. Monitors referring to odours were not more likely to make reports of any odour than those who did not. Monitors referring to the environment did not report all odours at differing levels to those not referring to the environment , but the number of landfill odour reports were significantly different. It is possible that concern about the local environment may have been a factor in monitors volunteering for the project. Three out of the four monitors who completed the post-monitoring questionnaire stated that such concerns were the reason behind volunteering. This may have implications for panel design. It may be necessary to conduct an attitudinal survey prior to monitoring, and certainly, enquire into monitors' opinions of the odour source and their neighbourhood, as they may have some form of personal agenda which affects their monitoring behaviour.
- The length of the time spent monitoring can influence the frequency of reports. New monitors produced markedly higher reporting intensities for all odours and landfill odours than long-term monitors.

It has become apparent that examining each factor in isolation from the rest is not a satisfactory approach to assessing the impact of odour in the community. Each monitor falls into different groups, male/female, older/younger, smoker/non-smoker and so on. Therefore each monitor has a variety of qualities that operate together at any one time, influencing odour perception. Some qualities may change with time, for example age, working patterns and health. It must be established how these attributes combine together to affect a monitor's reporting pattern in order to understand the impact of odour pollution. It is not simply a matter of attempting to quantify the quantity and quality of an odour at a given location from a source. It is important to have an understanding of the nature of the person perceiving. With this understanding of the qualities of the individual and their interaction with the environment, it should be possible to gain a more complete understanding of odour impact.

One of the conclusions from this thesis is that some form of multi-attribute analysis should be applied to further studies of this type. For the purposes of developing the framework as a whole in this research, the most significant sources of variability will be retained, but with some reservations.

Chapter 8

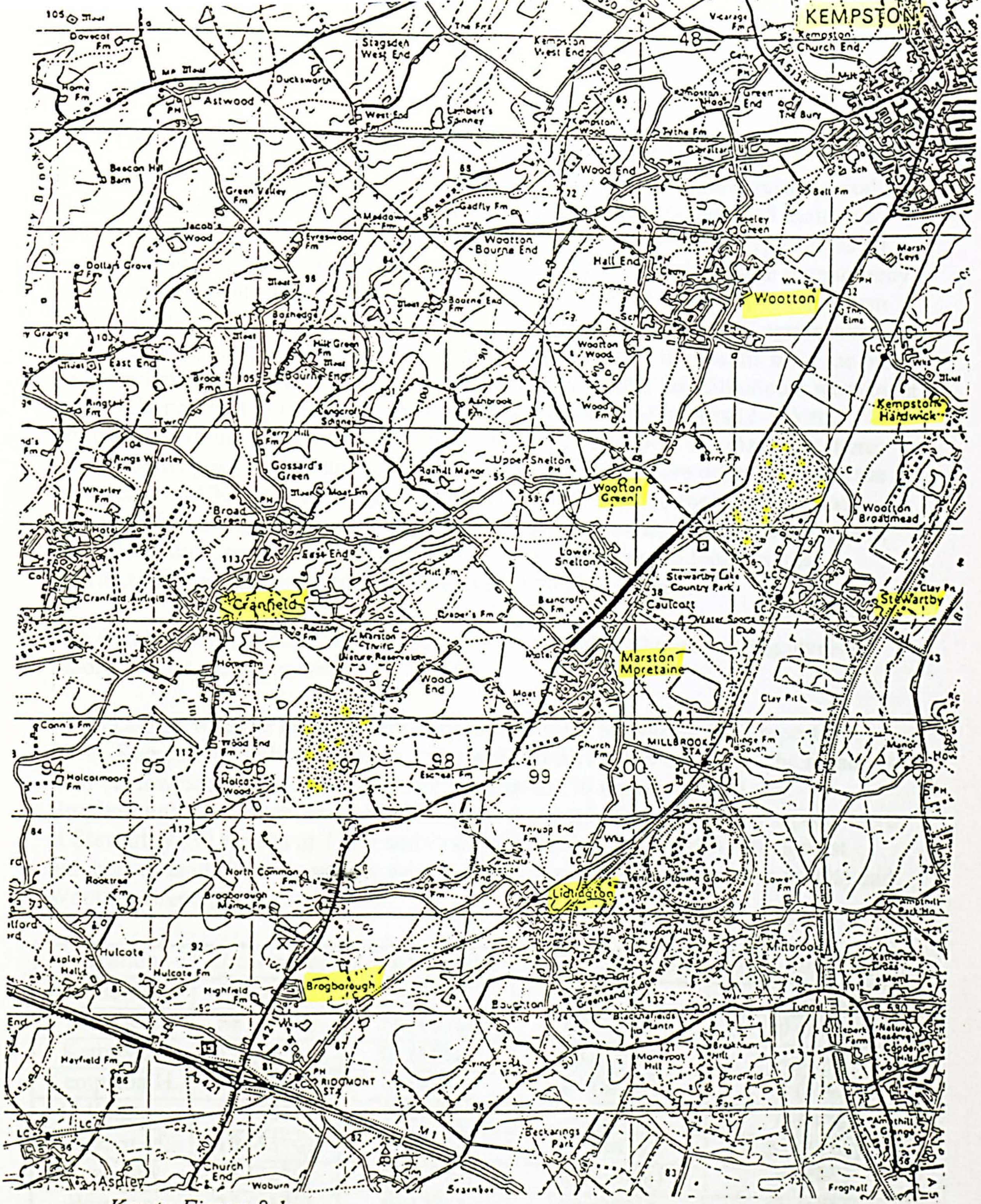
Reporting patterns across the Marston Vale

8.1 Introduction

In Chapter 7, the reporting patterns on the levels of individual and groups of monitors were examined. This chapter examines the overall impact of odour pollution in the Marston Vale on the basis of location (research objective 3). This forms the second stage of the development of the response framework. As discussed elsewhere in the thesis, spatial and temporal factors have been identified as affecting landfill odour pollution. In this chapter, the monitors' reports were broken down by location and the time they were recorded. This activity was undertaken, as with the groupings of monitors in Section 7.3, as illustrating the process of developing the framework. As with the data analysis carried out on the basis of individuals and groups. There were some difficulties encountered with assessment of the results on the basis of location. Notable examples are the presence of only one monitor at Marston Moretaine and the reliance on her reports, or there only being female monitors at Brogborough and Kempston Hardwick. As shall be seen, whilst they provide some insight into odour impact at those locations, there are constraints placed on the framework, such as the inability to estimate odour reporting intensities for males at Brogborough for example. Such a framework could be developed to be able to estimate reporting intensities at different locations. It could therefore be used within the context of the larger model illustrated in Figure 1.2, as it pertains to the highlighted area of that figure. Section 8.2 examines the pattern of results observed between April and July 1997 for all odour types and specifically landfill odour. Where necessary the results are compared to earlier reports (from the pilot panel, 1994 to 1997) and complaints. Section 8.3 concludes this chapter by discussing the implications of observed reporting patterns.

8.2 The overall pattern of results

It will be remembered from Sections 1.6 and 4.2 that the third research objective asked how spatial and temporal factors might affect exposure levels. Again the data from the pilot panel study indicated that there were certain settlements that experienced a higher frequency of particular odours. This section examines the overall results obtained during the monitoring period for all reports of odour and specifically landfill odours. It includes details of the numbers of reports made, the number of reports at each monitor location and the times and duration of the reports. The section is divided into two sub-sections, 8.2.1 that includes information of overall odour impact and 8.2.2 that examines landfill odour impact in particular. For ease of reference, a map of the Marston Vale is shown in Figure 8.1.



Key to Figure 8.1:

Landfill sites

Monitor locations

Figure 8.1: Map of the Marston Vale

Reproduced from the 1994 Ordinance Survey Landranger 1:50000 Map with the permission of the Controller of Her Majesty's Stationary Office, © Crown Copyright ED/96A

8.2.1 Overall odour impact in the Marston Vale April to July 1997

There were 796 reports of odour made during the three months monitoring period. Brickwork odour reports formed the greater number of reports with 315 incidents (39%) reported. This group was the most commonly reported odour type across all monitor groups. There were 283 local odour reports (35.5%). This large number may arise from the local category being a 'catch-all' for all other odour types other than those specified. There were 111 landfill odour reports (13.9%) and 87 agricultural odour reports (10.9%). This reporting pattern contrasts with the results from the pilot panel summarised in Table 5.2. The pilot study showed that landfill odours were most frequently reported (34%), followed by brickwork and local odours (27%) and agricultural odours (12%). Why this difference should occur is not clear, but there may be some possible explanations. The size of the panels were different, 19 in the pilot study and 30 in the redesigned panel. The distribution of the monitors was different; for example there were two monitors at Marston in the pilot study, one in the later study. Considering how impact may vary according to location, the distribution of monitors could affect the overall number of reports.

The different settlements where monitors were located produced varying levels of reports. These are summarised in Table 8.1.

The locations with the highest number of reports were Stewartby (177 reports or 22%), Kempston Hardwick (123 or 15%) and Cranfield (119 or 15%). The locations with the lowest number of reports were Lidlington (50 reports or 6%) and Brogborough (36 reports or 4%). The highest numbers of landfill odour reports were at Stewartby (30 reports or 17%) and Cranfield (22 reports or 18%). The lowest numbers of landfill odour reports were at Kempston Hardwick (5 reports or 4%) and Wootton Green (4 reports or 5%).

Location	Local odour	Landfill odour	Brickwork odour	Agricultural odour
Brogborough	**22 (61%)**	7 (19%)	**2 (5%)**	**5 (14%)**
Cranfield	**58 (49%)**	**22 (18%)**	**19 (16%)**	**20 (17%)**
Kempston	**19 (26%)**	**12 (16%)**	**38 (52%)**	**4 (5%)**
Kempston H.	**30 (24%)**	**5 (4%)**	**84 (68%)**	**4 (3%)**
Lidlington	**31 (62%)**	7 (14%)	**5 (10%)**	**7 (14%)**
Marston M.	**10 (13%)**	**16 (20%)**	**28 (36%)**	**24 (31%)**
Stewartby	**36 (20%)**	**30 (17%)**	**102 (58%)**	**9 (5%)**
Wootton	**27 (41%)**	**8 (12%)**	**20 (30%)**	**11 (17%)**
Wootton Gr.	**50 (67%)**	**4 (5%)**	**17 (23%)**	**3 (4%)**

Table 8.1: Breakdown of different odour types at monitor locations

It may be pointed out that it would not be feasible to assess the range of impact of most of these odour sources for the following reasons. The local and agricultural odours could not be examined as their sources are not known. It will be remembered that the local sources category included all odours not applicable to the other odour categories. It therefore included odours from domestic sources, such as garden bonfires, as well as commercial or industrial sources, such as garages, restaurants or traffic. In order for dispersion modeling to be undertaken the actual source and its location would have to be given. The nature and location of agricultural odour sources would also have to be specified. The landfill odours could not be easily assessed for reasons referred to earlier in the thesis (see Sections 3.3 and 4.3). The only source that could be assessed with some certainty would be the brickworks. This particular odour source is easily identified having clear emission points. Technically, it would be straightforward to obtain emissions data, such as times of firing, quantities of bricks fired, quantities of pollutants such as smoke and sulphur dioxide released, and rate of emission from the stacks.

As mentioned above, examination of the numbers of reports showed that the villages of Cranfield, Kempston Hardwick and Stewartby were the locations that produced the greater number of reports (119, 123 and 177 reports respectively). The mean numbers of reports per monitor were highest at Marston Moretaine, Kempston Hardwick and Stewartby (78, 41 and 35.4 reports respectively). However, as mentioned above, the mean number of reports does not reflect the extent of the impact of odour in terms of frequency of events.

Location	Total number of reports	Mean number of reports	Reporting Intensity value
Brogborough	**36**	**18**	**0.25**
Cranfield	**119**	**29.8**	**0.33**
Kempston	**73**	**14.6**	**0.22**
Kempston Hk.	**123**	**41**	**0.53**
Lidlington	**50**	**16.6**	**0.20**
Marston M.	**78**	**78**	**0.89**
Stewartby	**177**	**35.4**	**0.43**
Wootton	**66**	**16.5**	**0.20**
Wootton Green	**74**	**24.6**	**0.34**

Table 8.2: Total number of reports; mean number of reports and reporting intensities for monitor locations.

It also does not enable ease of comparison between locations where there are different numbers of monitors. When comparing the intensity values, it is apparent that the frequency of odour events is highest at Marston Moretaine, Kempston Hardwick and Stewartby. This is the same pattern as revealed by the mean number of reports. However, when the reporting intensity values for other settlements are examined, the two sets of values differ. For example, the settlement with the lowest mean number of reports is Kempston, yet the settlement with the lowest reporting intensity value is Wootton.

It is arguable on the basis of reporting intensities, that the settlements with the greatest extent of odour pollution are Marston Moretaine, Kempston Hardwick and Stewartby. Those with the least are Wootton, Lidlington and Kempston.

The numbers of overall odour reports and landfill odour reports were plotted against the date to identify any trends in the numbers of reports made over the monitoring period. The graph is shown in Figure 8.2.

Figure 8.2 shows the number of reports and a linear regression line for the total reports and landfill reports. As can be seen, there is a marked decline in the number of all odour reports over the monitoring period. There is a less marked decline in the numbers of reports of landfill odour. The regression lines themselves carried no weight statistically, and are included here only to illustrate the trend in reporting levels and as a demonstration that such analyses could be carried out in another study.

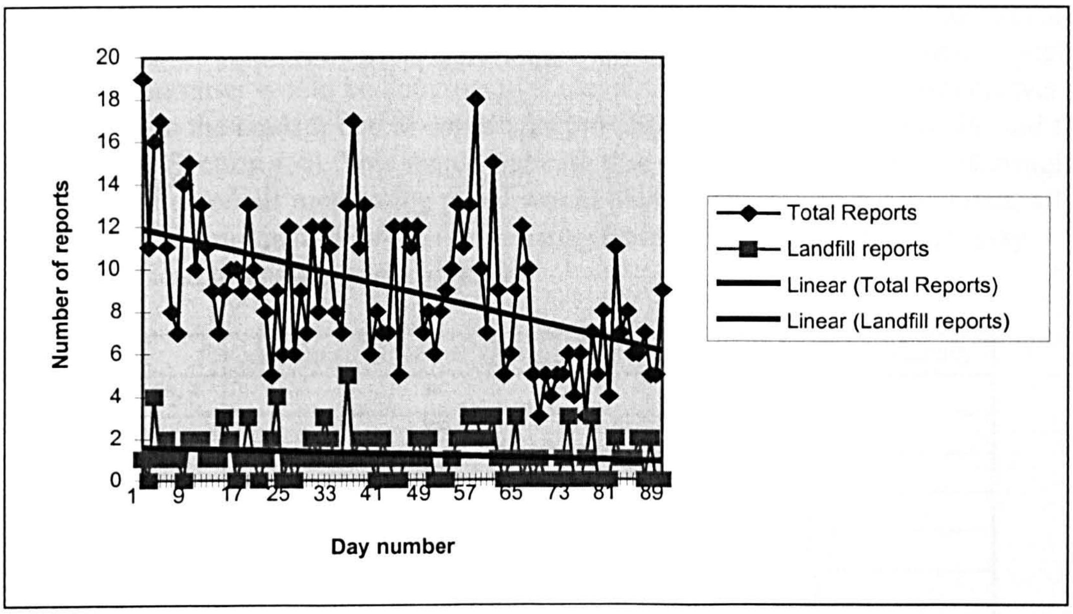


Figure 8.2: Trends in odour reports over the three month monitoring period

There are possible explanations for this pattern. Firstly, the influence of new monitors on reporting levels. Two-thirds of the panel was made up of new monitors who did produce higher levels of reports (see 7.3.7). As their initial enthusiasm or motivation wore off or as their experience as a monitor increased, they produced fewer reports, which had an effect on overall levels.

The prevailing weather conditions during this period may also have affected reporting patterns. For example, as mentioned in Section 4.4, it is known that if there is a temperature gradient between a warm waste mass and cooler air above, that thermally induced diffusion of volatile compounds can occur. Therefore as the weather warms, it would be anticipated that odour emissions would be more likely to occur. Baker and MacKay (1985) also discuss how landfill emissions may be higher in August than March, as there will be higher waste temperatures. Similarly, higher wind speeds may lead to more effective emission of odour causing compounds, as it would facilitate speedier evaporation from the waste surface.

When examining complaints data from Brogborough landfill site, there does not appear to be a clear picture of seasonal effects on odour impact. Searle (1994) in his report on odour problems at Brogborough provided a breakdown of complaints made between February 1993 and March 1994. The numbers of complaints are shown in Table 8.3.

The level of complaints varies throughout the year, but a peak period for complaints is from March to June. There is a peak in April (28 complaints) before complaints fall back in May and June (18 and 19 reports respectively) and then another fall in July occurs. There is a more confused picture from complaints data in the report by Van Harreveld (1997). These data were also collected from Brogborough over the period 1994 to 1996, broken down into quarters and is shown in Table 8.4. The first impression is that the number of complaints fell markedly from the previous year. The second impression is that the level of complaints does not fluctuate greatly during the course of the year, with marginally higher levels of complaints made in the first and fourth quarters. There is no peak occurring in the spring and early summer. A peak during the summer would be anticipated if elevated levels of odour emissions were released from the landfill due to conditions prevailing within the landfill site and the climate (see Section 4.4). This would indicate that odour impact can occur throughout the year and an odour monitoring panel would have to operate on a daily basis, all year round, and not just in periods which may be identified as those which may potentially lead to greater odour impact.

Month	All landfill odour complaints	Landfill gas complaints
February 1993	9	9
March	25	20
April	28	23
May	18	13
June	19	15
July	2	2
August	1	0
September	4	2
October	5	5
November	8	8
December	4	4
January 1994	11	0
February	0	0
March	1	1

Table 8.3: Complaints made to Brogborough Landfill 1993/94

	1st quarter	2nd quarter	3rd quarter	4th quarter
1994	5	2	6	12
1995	6	8	2	2
1996	5	3	5	5
Total	16	13	13	19

Table 8.4: Odour complaints made to Brogborough landfill 1994 to 1996

The data in Table 8.4 are also shown in Figure 8.3.

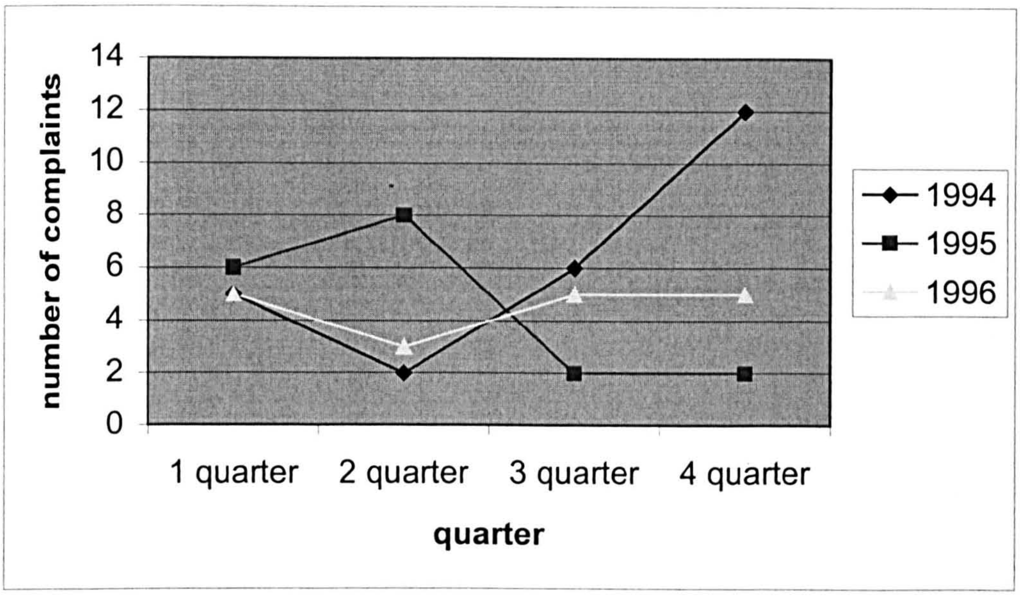


Figure 8.3: Numbers of complaints made 1994 to 1996

However, it may be remembered that complaints may not be a satisfactory reflection of the extent of odour impact. It was a reason for the introduction of an odour-monitoring panel. Therefore the trends in the odour monitoring reports between 1994, when the pilot panel was introduced, to 1998 were examined to identify any seasonal effects in reports of landfill odour. It should be remembered that the re-designed panel was introduced in April 1997, accounting for the sudden rise in numbers of reports. The values of all odour and landfill odour reporting intensities are shown in Table 8.5. They are shown graphically in Figures 8.4 and 8.5.

	1st		2nd		3rd		4th	
	All odour	Landfil odour	All odour	Landfil odour	All odour	Landfil odour	All odour	Landfil odour
1994	**0.044**	**0.0**	**0.054**	**0.0**	**0.11**	**0.03**	**0.10**	**0.035**
1995	**0.06**	**0.02**	**0.10**	**0.03**	**0.11**	**0.02**	**0.08**	**0.02**
1996	**0.07**	**0.02**	**0.10**	**0.01**	**0.13**	**0.02**	**0.09**	**0.01**
1997	**0.10**	**0.02**	**0.32**	**0.04**	**0.28**	**0.05**	**0.22**	**0.05**
1998	**0.23**	**0.06**	**0.22**	**0.05**	**0.24**	**0.08**	**0.24**	**0.11**

Table 8.5: Quarterly reporting intensities produced from 1994 to 1998

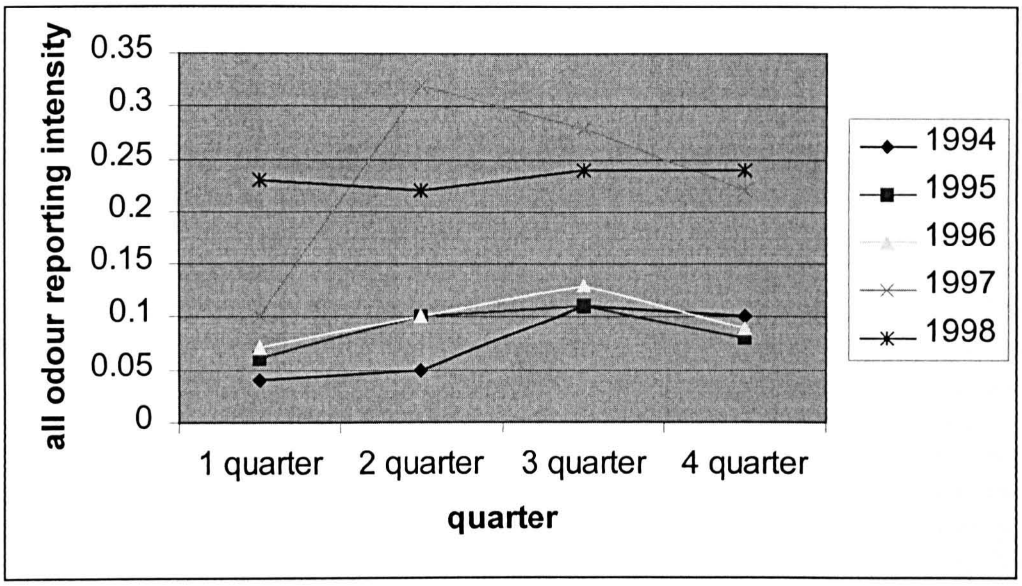


Figure 8.4: All odours reporting intensities 1994 to 1998

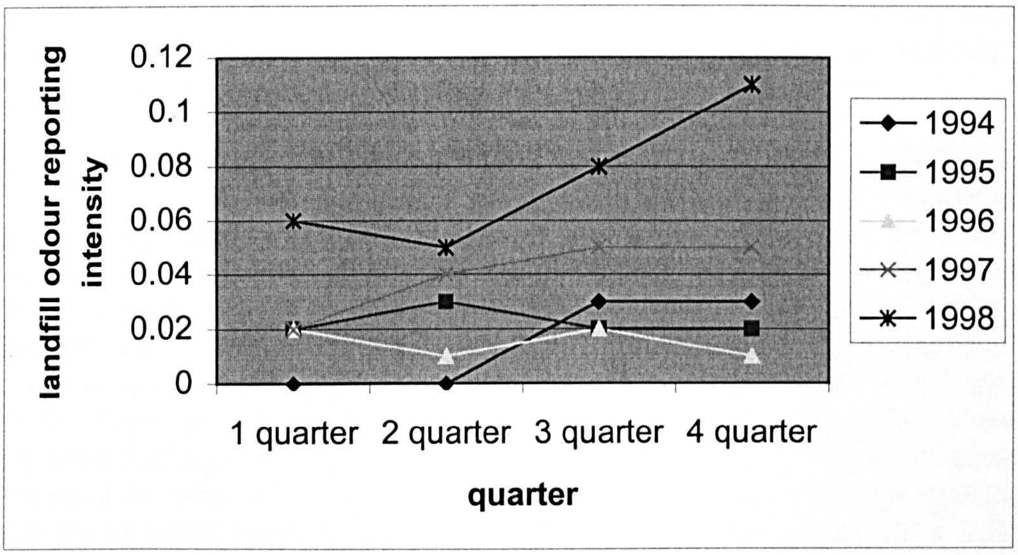


Figure 8.5: Landfill odour reporting intensities 1994 to 1998

The overall odour reporting intensities for 1994 to 1996 and 1998 peaked in the third quarter (July to September). The exception to this was 1997, where the peak was greatest in the second quarter (April to June). A simple explanation for this may be the panel being increased in size with new monitors in April 1997. It is notable that the number of reports made by new monitors tailed off throughout the April to July monitoring period. The level of the reports for this quarter therefore may be an exception to lower levels in other years. The indication from the reporting intensities is that odour nuisance is more likely in the summer months. This differs from the level of complaints, which remained constant throughout the year, with a slight increase in the fourth quarter (Table 8.4 and Figure 8.3). It is possible that using report intensity values may be a more subtle means of assessing impact as it reflects the number of reports made over the number of days monitors were active. Complaints do not reflect these temporal aspects of exposure so well. Whether this is the result of climatic conditions influencing the odour sources and odour dispersion, particular processes being notably active in producing odours, or the monitor's behaviour, or a combination of all of these factors is not clear.

When comparing the complaints from 1994 to 1996 with reports made during the same period, there is some similarity in pattern throughout the year. In 1994, complaints fall between the first and second quarters, before rising throughout the rest of the year. "All odour" reports and landfill odour reports do not fall between the first and second quarter, but they do rise between the second and third quarters. There is no increase between the third and fourth quarters. There appears to be similar patterns in 1995 and 1996, where levels of reports and complaints coincide at certain times but not at others. In 1995, there is some agreement between reporting intensity and complaints. The levels of reporting intensities for "all odours" and landfill odour, and complaints increase between the first and third quarters, before falling back through the rest of the year. "All odour" reporting intensity levels differed from landfill odour intensity and complaints. "All odour" intensity reports increased between the first and third quarters, before falling. Landfill odour and complaints levels fell between the first and second quarters, increased between the second and third quarters and fell between the third and fourth quarters. This comparison serves to illustrate that there is a general relationship between reporting intensities and complaints. As referred to above, however, complaints do not relate temporal effects as well as reporting intensity values.

The landfill odour reporting intensities showed a different pattern. In 1994, reporting intensities were highest in the last two quarters of the year. In 1995, the peak period for reporting intensity was the second quarter; values remained constant throughout the rest of the year. The highest values were recorded in the first and third quarters in 1996. In 1997, levels of reporting intensities rose throughout the year. Reporting intensity levels fell between the first and second quarters before rising again to a new peak. No seasonal trends appeared to occur. If higher temperatures caused higher levels of emission of odours, as suggested by Baker and MacKay (1985), it would be expected that higher intensity levels would occur in the second and third quarters (see Section 4.4). However, like the complaints data, no one year showed this pattern. As with the all odour intensity values, the patterns seen may have arisen for a number of reasons. The weather may affect landfill odour evolution, release and dispersion. It is likely that these processes are affected by several climate parameters, for example, temperature, atmospheric pressure or wind speed acting together, rather than singly. Additionally, the behaviour of monitors will change throughout the year, being indoors or outdoors for example, which will also affect their reporting patterns. These behavioural factors are discussed in greater detail below.

An effort was made to outline a profile of odour events in terms of the days and times when they are most likely to occur and their duration. The numbers of odour reports made on different days of the week are shown in Table 8.6.

The largest numbers of reports were made on Mondays, Tuesdays and Fridays. The lowest number of reports was made on Sunday. This low level of reporting on Sundays may result from certain businesses not operating on Sundays, hence the lower level of reports from local and agricultural sources. However, reports from landfill and brickworks are less variable with levels of reports remaining constant during the week.

	Local odour	Landfill odour	Brickwork odour	Agricultural odour	Total
Monday	**49**	**22**	**35**	**18**	**124**
Tuesday	**52**	**18**	**45**	**12**	**127**
Wednesday	**38**	**14**	**53**	**10**	**115**
Thursday	**45**	**17**	**35**	**13**	**110**
Friday	**38**	**16**	**56**	**15**	**125**
Saturday	**38**	**12**	**46**	**11**	**107**
Sunday	**23**	**12**	**45**	**8**	**88**

Table 8.6: Days when odour reports were made

The times of the odour reports are shown in Figure 8.6,

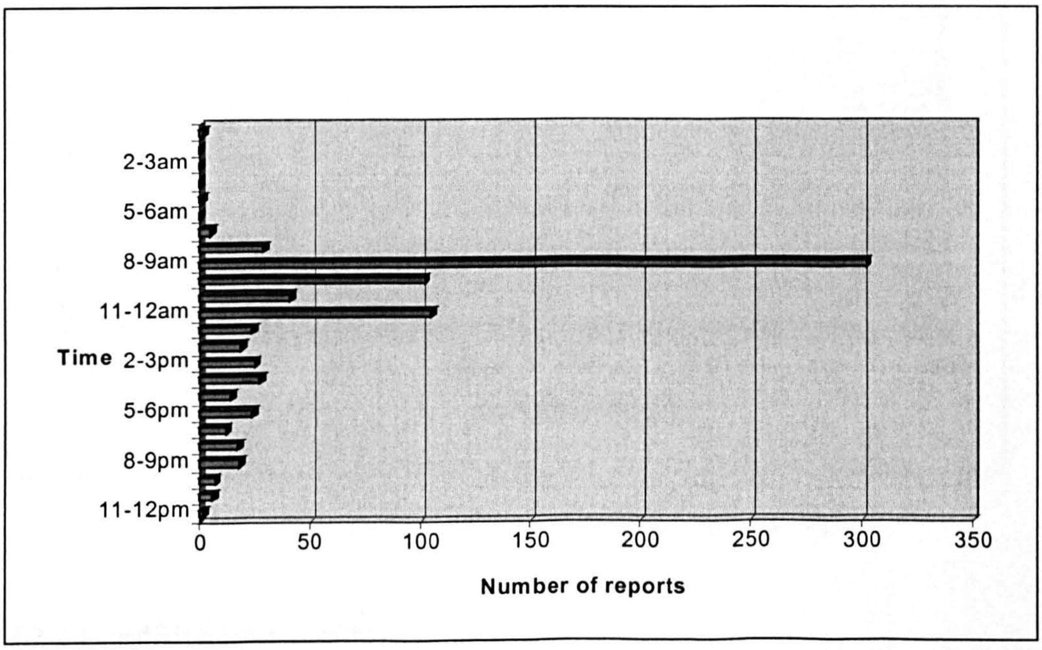


Figure 8.6: Time of day when odour reports were made

It can be seen that the most frequent time for reports was between 8 to 9am. Two monitors carried out their regular sniffing for odours between 11 to 12am, which goes some way to explain the second peak at that time. There were fewer reports of odour very early in the morning or in the late evening, possibly as a result of fewer monitors being up and about at those times. There were more reports of odour in the morning than at any other time of day, although there were smaller peaks at around 2 to 4pm and 5 to 6pm. This may be associated with monitors coming home from work at around those times. There may also have been an association between reports and prevailing weather conditions. Wind speeds are lowest in the mornings and afternoons during this period. In Section 8.4, the apparent relationship between lower wind speeds and reports is highlighted. It will be shown that researchers have found that wind speeds are critical in dispersion processes. If winds exceed $3m/s^{-1}$, effective dispersion of pollutants will occur. Speeds below this threshold result in ineffective dispersion (Nkemdrim 1988).

The monitors were asked to state how long they could detect the odour. The results are shown in Figure 8.7. Most of the reports made did not include the duration of odour. These reports are shown in the 'not stated' category. Of the reports that did include details of the duration of the odour, the majority of odours were detected for up to 5 minutes. Fewer odours were detected which persisted between 10 and around 25 minutes. However there were a substantial number of reports that stated that odours persisted for between 30 minutes and all day. This suggests that odour events, when they occur, are either fleeting in nature or can be persistent for long periods of time. Or conversely, it may be the result of some people being around for longer or shorter periods.

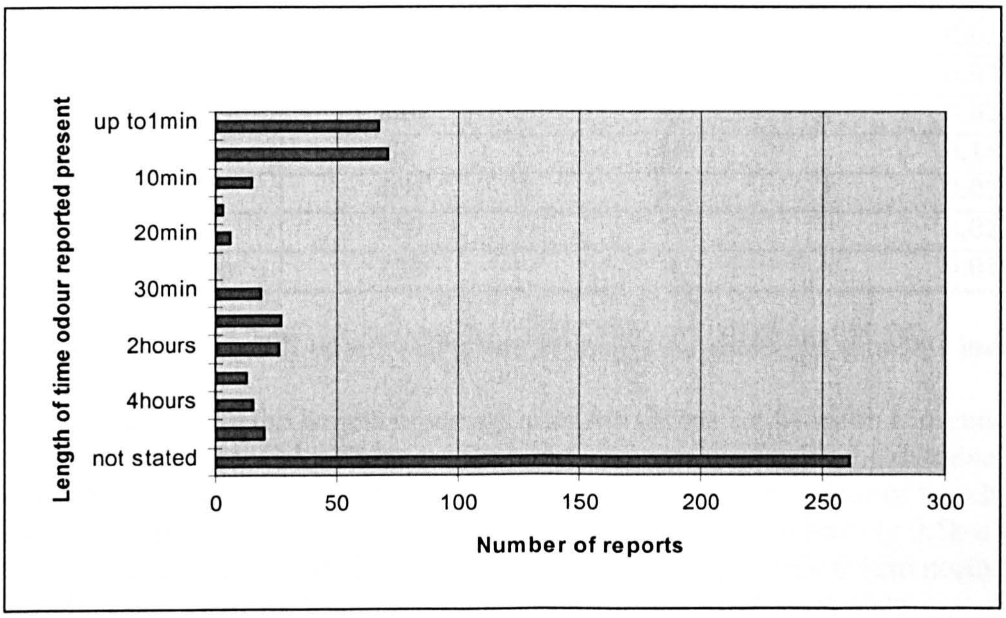


Figure 8.7: Duration of all odour reports

8.2.2 Landfill odour reports

Landfill odour reports were reasonably consistent throughout the week. The days when reports were most frequent were Monday and Tuesday and were lowest on Saturday. Reports of landfill odour were most frequent in Cranfield, Stewartby, Marston Moretaine and Brogborough. They were least frequent at Kempston Hardwick and Wootton Green. The landfill odour reporting intensities for each location were calculated and are shown in Table 8.7 below. It will be noted from 8.2.1 that there was no clear cut pattern in the distribution of landfill odour reports. Cranfield and Stewartby may experience odour pollution frequently as a result of close proximity to the two landfill sites. But this cannot explain lower reporting levels at Kempston Hardwick that is close to the Lfield site and northeast from it, that is downwind in the direction of the prevailing wind. This pattern of reporting may have arisen from two factors. Firstly, that the numbers of monitors were too small to successfully differentiate areas with greater or lesser areas of impact. Conversely, this confused pattern may be a satisfactory reflection of odour impact and illustrates the complexity of pollution dispersal. If this is the case then it is apparent that there will be consequences for issues of panel design. There may be a requirement for a minimum number of monitors to be present at each location. For example there were three monitors at Kempston Hardwick, which was thought originally to be sufficient. However, this may not be a large enough number of people to assess odour impact satisfactorily. It may suggest that all efforts should be made to encourage a diverse group of individuals to monitor for odours. It is notable that all the monitors at Kempston Hardwick were females who worked full-time. Alternatively, there may have to be a change in the monitoring procedure and data recording, for example, monitors having to sniff for odours more than once a day.

Location	Reporting days	Landfill odour reports	Landfill odour intensity
Brogborough	142	7	0.049
Cranfield	356	22	0.062
Kempston	325	12	0.037
Kempston Hk	231	5	0.022
Lidlington	254	7	0.027
Marston Moretaine	88	16	0.180
Stewartby	406	30	0.074
Wootton	339	8	0.023
Wootton Green	220	4	0.018

Table 8.7: Landfill odour reporting intensity for different monitor locations

The locations with the largest reporting intensity values are Marston Moretaine, Stewartby and Cranfield. These results should be compared with the distribution of complaints during the same period. Six complaints were made, four of which arose in Marston Moretaine. The other two were at Wood End (approximately 0.5km north-east of Brogborough landfill) and Rectory Farm (approximately 0.5km north-west of Brogborough landfill). Refer to Figure 8.1, a map of the Marston Vale.

The data from reports pertaining specifically to odour from landfill sites were examined for times and duration for comparison with the data for all odour reports. This was done in order to ascertain if the pattern of landfill odour reports followed that of all odour reports. Landfill odour times are shown in Figure 8.8 and duration of landfill odour events is shown in Figure 8.9.

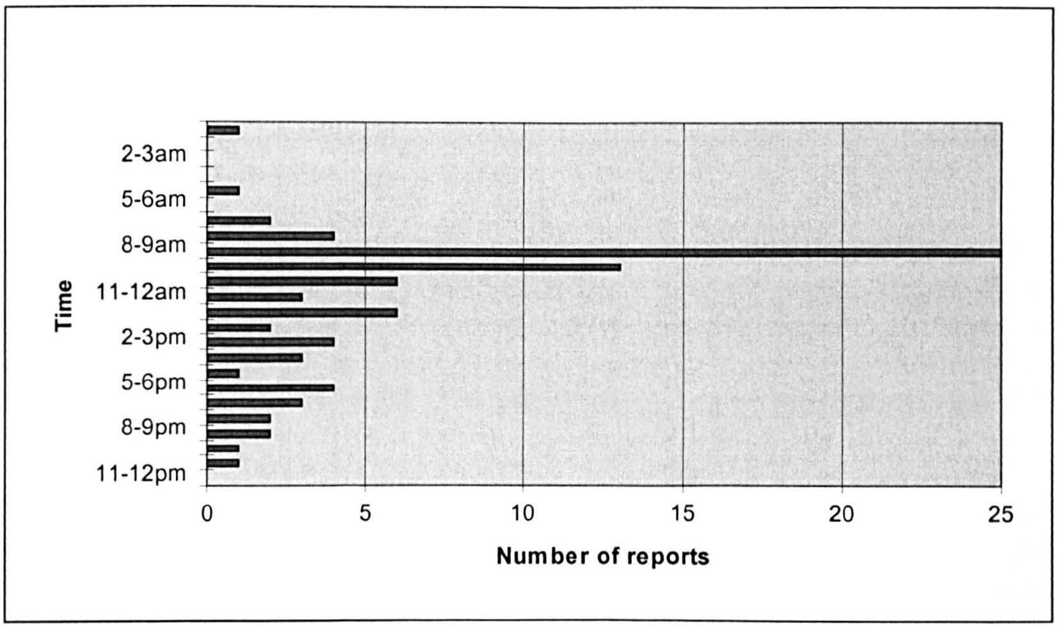


Figure 8.8: Times of landfill odour reports

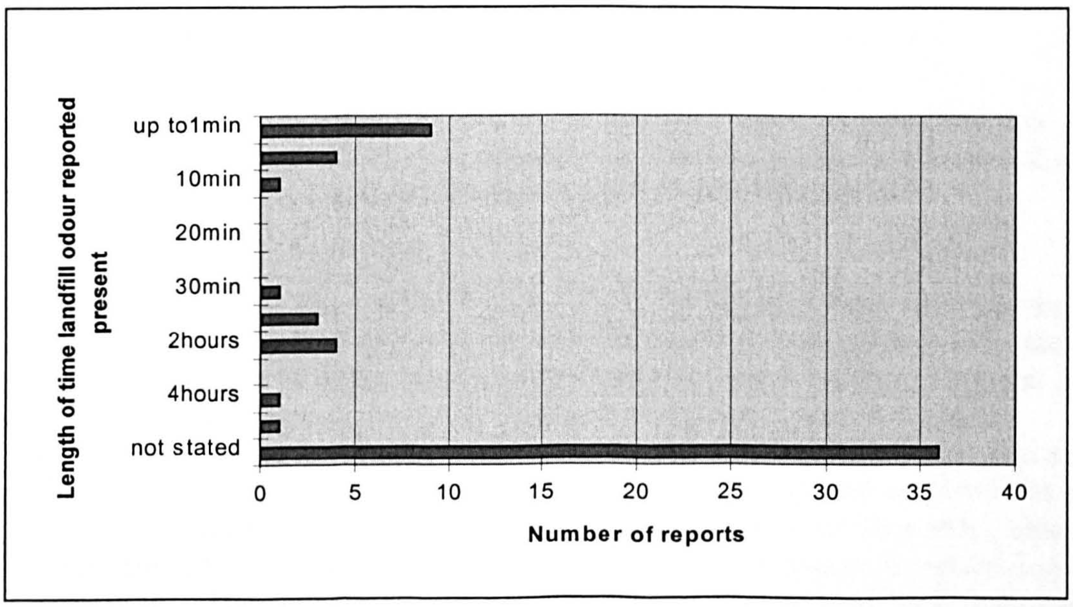


Figure 8.9: Duration of landfill odour events

As with all odour reports, landfill odour was most frequently reported between 8 to 9 am. The reporting pattern was similar, with smaller peaks occurring at 2 to 4pm and between 5 to 7pm. This pattern probably arises for the same reasons as all odour types.

As with the reports relating to all odours, the majority of reports did not include details of the length of time the odour could be detected. The duration of landfill odour incidents was similar to those of all odours, although the category of odour being present for up to one minute was the larger category. Again there were few reports where odour was reported as being present between 10 to 30 minutes and then more reports where odour was reported as being present from 30 minutes to all day.

8.2.3 Conclusion to Section 8.2

It can be seen from the information above that the levels of reports of odour vary across the Vale. The different monitor locations have produced varying levels of different odour reports. This suggests that different locations not only experience varying levels of overall odour pollution, but different locations experience varying levels of different odour types. For example Kempston Hardwick produced 15% of all odour reports. Of these reports, 68% were brickwork odour. Cranfield produced 14% of all reports, a similar level to Kempston Hardwick. However, the largest category of reports was local odours (52%). The level of landfill odour reports varied between the two settlements. Kempston Hardwick produced the lowest levels of landfill odour reports (5 reports or 4%), whilst Cranfield produced one of the highest totals (22 reports or 20%).

There were some features common to the reports. There were, for example, times when odours were reported more frequently. These were mid-morning, between 8 and 10am, and around 2 to 3pm and 5 to 6pm. The odours were also reported as being detectable for either short periods of a few minutes or being present for half an hour or longer.

8.3 Summary and Implications of observed reporting patterns

As with examining reports on the basis of individuals or groups of monitors, it is apparent that reporting levels across the Marston Vale vary, both by location and over time. Similarly, the relationship between reports and complaints is not straightforward.

When considering the importance of location it is apparent that there were varying levels of overall reports of odours at the nine different locations. Additionally, there were different levels of different odour types reported at each location. This may arise due to proximity to a particular odour source. For example, the most frequently reported odour source at Kempston Hardwick was that of brickwork odour. This may not be surprising when a small brickwork site is located within 100 to 200 metres of the monitors' homes. The same could be said of the settlement of Stewartby, which also contains a brickwork site. It also worth considering the impact of meteorological factors on the effect different odours have on each monitor location. At Brogborough and Lidlington, the most frequently reported odours were local odours. Brickwork and landfill odours formed 24% of all reports. The settlements are located upwind of both these types of odour source.

Examining the times of reports showed the morning to be the time of day when most reports were made, even though monitors were at home for shorter periods than at any other time of day. Additionally, the duration of odour events was, largely, brief, lasting only a matter of minutes. This could be due to environmental or behavioural factors on the part of the monitors or both. Odours may be more easily detectable in the morning due to atmospheric conditions. Oke (1993) discusses an example of this when examining plume patterns under different atmospheric conditions, one of which is referred to as fumigation. This occurs when there is what Oke calls an inversion 'lid' above a plume preventing upwards dispersion, but with unstable air beneath the lid permitting mixing and dispersion of a plume at ground level. Oke relates how this could take place in a number of ways, such as in rural areas after sunrise when a nocturnal surface inversion is eroded by surface heating. The movement of pollutants in the atmosphere is strongly affected by prevailing conditions within the boundary layer, the layer of air closest to the Earth's surface. This layer is characterised by turbulence generated by frictional drag as the atmosphere moves across the Earth's surface and receives most of its heat through this turbulence (Oke 1993) The height of this boundary layer varies with the strength of surface mixing. For example, during the day, there is an upward transfer of heat to the cool atmosphere from the surface of the Earth as it is heated by the sun. This vigorous mixing can cause the boundary layer to rise to 1 to 2km. At night and with cooling of the ground, mixing is limited and the boundary layer can shrink. It is variation in the stability conditions of the boundary layer that can affect dispersion of pollutant plumes. Ordinarily, the best conditions for dispersion of pollutants are when there is a deep boundary layer with strong instability. These conditions develop in sunny daytime conditions, notably in the summer. Conversely, the worst conditions for dispersion are when there is a stable boundary layer with a temperature inversion where temperatures increase with height, rather than fall. This results in little if any turbulence and upward movement, resulting in dispersion and dilution being limited (Oke 1993). Additionally, monitors will be exposed to odours present for the first time that day and will not have adapted to them. Hence they may be more likely to notice odours. Also monitors may be more likely to go outside in the morning, even if it is to travel to work, take children to school or go shopping. When examining the diary data, it was notable that many reports were made within a short time of getting up, or leaving or returning home. This will have consequences for the design of monitoring panels. As individuals may appear to be most likely to detect odours in the morning, is it desirable for them to be asked to detect odours in the morning. This would depend on what is required from the monitoring data; either personal exposure through the day or identification of all odour incidents

Climatic factors may influence the length of time an individual may experience an odour. If, for example wind speeds are high, an odour plume will be dispersed rapidly causing little nuisance. It was noted in Section 8.2, that all complaints and 95% of reports were made when wind speeds were no more than $9m/s^{-1}$ (see Section 9.8 for further discussion). The brief periods when odours are perceived may result from this rapid odour dispersion. Alternatively, there may be behavioural factors involved. Monitors may briefly detect odours due to their moving indoors or leaving the area. They may also 'catch' the tail end of a plume as it travels through the environment. On the other hand, when long periods of odour pollution are referred to this may arise due to environmental and behavioural factors also. Atmospheric conditions may result in little dilution or dispersal of the odour plume. Monitors may be outside for long periods of time or travel between the indoors and outdoors frequently during the day. These factors may combine to produce an odour event for the respondent lasting some hours. Adaptation to an odour may take place, but if the properties of the odour change, for example its concentration or hedonic qualities resulting in an odour becoming more intense, it may remain detectable.

When reflecting on the results from Chapter 7, which reviewed reporting on the basis of individuals and groups, and from this chapter, examining reports on a spatial and temporal basis, it is apparent that there is no clear cut pattern of exposure. Certain settlements appeared to be more frequently affected than others by odour pollution, for example Lidlington and Stewartby. Similarly, certain types of individual appeared to be more likely to experience odour pollution than others, for example, individuals with health problems affecting their sense of smell. There was no overall blackspot or group more or less likely to be affected by odour. This, perhaps is a reason to attempt to model population exposure in order to ensure that over- or underestimation of odour pollution impact does not occur.

8.4 Conclusions

As stated at the beginning of the chapter, the analysis of monitors' reports involved assessing the importance of spatial and temporal aspects of odour pollution impact. The results are summarised below.

- The levels of reports and types of odours reported varied across the Marston Vale with Stewartby producing the highest level of landfill odour reports and Wootton Green the least.
- Overall odour reporting intensities also varied. Marston Moretaine, Kempston Hardwick and Stewartby producing the highest values, and Wootton and Lidlington the smallest.
- Landfill odour reporting intensities were highest for Marston Moretaine and Stewartby and lowest for Wootton Green.

This illustrates that the experience of odour varied across the Marston Vale, with some areas more adversely affected than others.

- The levels of overall odour reports and landfill odour reports fell over the monitoring period.

This pattern may have arisen due to monitor reporting fatigue. It suggests that monitors may have a "lifespan", after which they would have to be removed from the panel due to loss of motivation. The possible methods of managing monitors and assessment of their reports are examined in Chapter 9.

- Complaints (between 1993 and 1997) and reports made between 1994 and 1998 showed differing patterns. Complaints largely appeared to be constant throughout the year. Reports suggested a possible peak period during the summer. It should be noted that complaint and report patterns varied on a yearly basis.

This result reflects the suspicions held by some researchers that complaints may not reflect the true extent and frequency of odour events.

Chapter 9

Assessment of data reliability

9.1 Introduction

In this chapter, a review of methods that were used to assess monitors' data and their performance as monitors are highlighted. The purposes behind this activity are twofold. Firstly, to ascertain some idea of the levels of reliability of each monitor's reporting patterns. It was hoped to identify monitors who may have been more likely to produce less reliable reports. There was a great deal of reliance on the monitors' reports to identify variability in response and to illustrate how to develop a population response framework. Therefore some form of "quality control" of these reports was required. Secondly, to indicate how such assessment of report reliability could be undertaken if further uses of monitoring panels are undertaken. This is particularly the case if, as with the panel used in this research, monitors are left to themselves to make reports and are not directly supervised. It would be necessary if organising a monitoring panel to identify ways of ensuring that reports would be reliable.

In Section 9.2, the categories used by individual monitors to describe cloud and visibility at the time of their landfill odour report are compared with those of other monitors reports made at the same time. In Section 9.3, the reporting patterns of long-term and new monitors are re-examined. It will be noted from Section 7.3 that reporting patterns of long-term and new monitors varied, with long-term monitors producing fewer reports and consequently lower reporting intensities. In Section 9.4, complaints made to the landfill operator during April to July 1997 are examined to identify any occasions where they coincided with monitors' reports. In Section 9.5, the absence levels of monitors are examined and in Section 9.6, the results of the post-monitoring questionnaire are presented. Finally, in Section 9.7, the monitors landfill odour reports are compared to both wind direction and wind speed.

9.2 Monitors' selection of cloud and visibility category

Reports made over the period of approximately an hour, for example 8.00am to 9.00am, on the same day were examined for the cloud and visibility level (c and v) described by the monitors. These data were extracted from the database in which the reports had been recorded. They were extracted using the query facility asking for details of date, time, cloud and visibility, and the monitor's reference code and in this case examined by eye. There were 159 occasions over the three months, where two or more monitors made reports at approximately the same time. It will be remembered that the monitors were assigned a set monitoring time, at around 8.00am, when they were asked to sniff the air. The majority of occasions when reports were made at the same time were at this set time (84 times). The number of occasions where 1, 2, 3 or 4+ categories were used is shown in Table 9.1.

	1 c&v category used	2 c&v category used	3 c&v category used	4+ c&v category used
Number of times referred	**33**	**64**	**43**	**19**
%age	**21**	**40**	**27**	**12**

Table 9.1: Number of cloud and visibility categories used

- Where more than one category of c and v were used, there were 36 occasions where the categories referred to were not sequential, for example categories 1, 2, 3 or 4 and 5. This includes 7 occasions where categories 6,7 or 8 were used when other values other values were 4 or less. There were no occasions where low category values of 1,2 or 3 were used at the same time as high category values.

- 25 monitors made reports when 4 or more c and v categories were referred to. Some monitors made reports more frequently than others under these circumstances. These include monitors CFS (13 times), SRWG (13 times), NHTC (15 times) and SWS (18 times) Other monitors ranged between once to 8 times.

- There were 7 occasions where there were outlier c and v values, that is where a 6, 7 or 8 category when other categories were 4 or under. The monitors responsible for this were JBS (I outlier), CFS (2 outliers), SRWG (1 outlier), NCL, VHB (two outliers) and SWKH (3 outliers). When other reports made at the same time were examined, it was noted that there were no other monitors at the same location with whom reports could be compared, apart from the following occasions. VHB and NCL both reported cloud and visibility as 8 on 25 and 26 April. They live at Brogborough and Lidlington, which are both situated at the south of the Vale, and possibly may have experienced foggy weather, unlike other monitors to the north. Monitor SWKH also produced extreme c and v reports on 27 April, 4 May and 12 June. On 27 April, there were no other odour reports at Kempston Hardwick, but a monitor at Stewartby reported c and v as 3 and a monitor at Cranfield reported the level as 4. On 4 May, another monitor at Kempston Hardwick, IKFKH, reported odour at the same time as SWKH, and reported c and v as 4. The range of c and v chosen at that time by other monitors was 4 (two reports) and 3 (one report). On 12 June, two monitors at Stewartby reported cloud cover as 3 and 4. It is apparent that SWKH was not an accurate reporter of c and v. If this is the case there is the possibility that other details of her reports may not be accurate.

It is apparent from this checking procedure that one monitor, SWKH, produced reports which could have contained inaccuracies. Checking of data should be undertaken as part of panel management, in order to identify monitors who may make mistakes in their reports. It would be convenient to undertake this process when checking monitors reports when they are long-serving monitors or when identifying if the length of time spent in the area is assessed to see if it affecting reporting patterns.

9.3 Long-term and new monitors' reporting patterns

It will be remembered that there were ten monitors who had monitored for the pilot study panel and twenty monitors started monitoring in April 1997. In 7.3.7, it was noted that long-term monitors produced lower numbers of overall odour and landfill odour reports and consequently reporting intensities than did new monitors. Table 7.27, shows reporting intensities for overall odour and landfill odour reports is reproduced in Table 9.2.

	Reporting days	Overall reports	Reporting intensity	Landfill reports	Landfill intensity
Long-term monitors	792	124	0.16	25	0.03
New monitors	1636	672	0.41	86	0.05

Table 9.2: Reporting intensities of long-term and new monitors

As discussed in 7.3.7, this pattern may have arisen for different reasons. Long-term monitors may have experienced loss of motivation with monitoring over a long period. Alternatively, they may be more inclined to use their judgement about whether or not to report odours. As stated in 7.3.7, it would appear that monitors should not be retained in a panel. It is necessary to periodically review the levels of reports, for example six-monthly or annually, to ensure that fatigue is not missed. As soon at it is identified, the monitor concerned should be removed from the panel. It was also noted that the level of reports made by new monitors also fell during the monitoring period. This may have illustrated that even new monitors may have started to experience fatigue or began to apply their judgement more frequently about reporting. Again their reports should be closely examined and if the trend continued, they too should be removed from the panel.

9.4 Complaints made to the landfill operator April to July 1997

There were six complaints relating to landfill odours made to the landfill operator during the monitoring period. These are summarised in Table 9.3.

It can be seen that there were three complaints arising at the Brogborough site and three at the Lfield site (two of the Lfield complaints, on the 28 May and 2 June relating to the chemical plant, were made from the same address). The monitors' report sheets were examined for reports of odour that were recorded on the same day as the complaints. Reports occurring on the same day as the complaints are also shown in the table.

The monitoring panel was in operation for three months. As the panel ran for a short period and the number of complaints was so small, no trends or relationships could be identified. During this time, six complaints were made, four (60%) of which coincided with reports made by monitors. It should be noted that nothing was known of the individuals making the complaints apart from their location. Nothing was known either of whether they had complained previously.

Date	length of time	Complaint made at	Complaint location	Cause of complaint	Report at location	Monitor initials
20/5	**pm**	**Brogboro'**	**Rectory Farm**	**trench?**	**Kempston**	**PFK**
20/5	**all day**	**Brogboro'**	**Wood End**	**No smell on site**	**Kempston**	**PFK**
26/5	**am**	**Brogboro'**	**Marston**	**No smell on site**	**Cranfield**	**NHTC**
28/5	**am**	**Lfield**	**Marston**	**chemical plant**	**No report**	
28/5	**pm**	**Lfield**	**Marston**	**no gas control**	**No report**	
2/6	**pm**	**Lfield**	**Marston**	**chemical plant**	**Wootton** **Wootton G**	**ERW** **FLWG**

Table 9.3: Complaints made to Brogborough and Lfield sites during the monitoring period

Bearing in mind the historical complaints data examined in Section 8.2 and how there was no close agreement between complaints and reports, the above table shows that during the monitoring period the same pattern continued.

9.5 Absent monitors

In this section, the number of reporting days for monitors are examined in detail to identify if absence rates affected the numbers of reports made. Monitors were asked to state when they were absent or unable to make a report. It was noticed that the new monitoring method resulted in more complete reports. The reports during the monitoring period were examined for the numbers of days monitors did not submit reports. The numbers of days absent varied from none for six monitors to 31 days for monitor CCB, a long-term monitor. The numbers of days when reports were not made are summarised in Table 9.4.

Number of absent days	Number of monitors
0 - 10 days	20
11 - 20 days	5
21 - 30 days	5

Table 9.4: Number of days monitors reported absent

The majority of monitors were absent only for up to 10 days during the monitoring period. Five monitors were absent for between 21 to 30 days. Of these five monitors, three were long-term monitors, all of them were female, two were full-time workers, one part-time and two were housewives. A brief examination of the reports of absence and the types of monitors who made them was carried out in order to identify if there were particular types of monitor prone to absence.

In order to do this, the monitors were divided into groups that were identified in previous sections, which may have differing periods of time at home, and the number of absences for each group obtained. They were monitor location, gender, length of time monitoring, age and employment pattern. The absence rates in monitors at each settlement were counted up and are listed in Table 9.5 shown below,

Settlement	Number of monitors	Total absent days	Mean number of absences
Brogborough	2	40	20
Cranfield	4	8	2
Kempston	5	56	11.2
Kempston H'wick	3	42	14
Lidlington	3	19	6.3
Marston Moretaine	1	3	3
Stewartby	5	49	9.8
Wootton	4	25	6.25
Wootton Green	3	53	17.7

Table 9.5: Levels of absent days at each settlement

It can be seen that the mean number of absent days varied markedly with each settlement, from two at Cranfield to 20 at Brogborough. It should be noted that one of the monitors at Brogborough had the highest level of non-reporting days during the monitoring period.

The number of days long-term and new monitors were absent were 116 and 179 days respectively. The mean number of days absent were 11.6 for long-term monitors and 9.4 for new monitors. The values did not appear to be too different, suggesting that absence levels were similar for both groups, with a slightly higher level for long-term monitors. A student t-test was carried out to confirm the null hypothesis that there was no difference between the mean values. A test value of -0.77 was obtained. As the critical value was 2.13, the null hypothesis was accepted and therefore it was concluded that there was indeed no difference between the mean values of the two groups. It is noteworthy that the reporting intensities for new monitors were higher than for long-term monitors, even though the absence rate for both groups was the same. This would suggest that absence did not affect levels of reports.

Absences for male and female monitors were 58 and 237 days respectively, and the mean values were 7.2 and 11.3. This suggests that female monitors were more likely to be absent than male ones. Again, a student t-test was conducted with the null hypothesis that there was no significant difference between the mean absence rates of the two groups. The t value of 1.96 was greater than the critical value of 0.09, which indicated that there was a significant difference between the male and female reporting rates. Female monitors appeared to be more likely to be absent than males. However, again the level of absence did not appear to affect the reporting intensities of the two groups. Although males reported landfill odours most frequently, females reported all odour types most often.

The age group 18 to 35 years had 73 days absent (the mean value was 9.1). The next group, 36 to 45 year olds, were absent 91 days (mean number of absent days was 15.2). The final group, 46 to 55 year olds, were absent for 107 days (mean number was 9.7), and the 56+ year olds were absent for 24 days (mean number of absent days was 6). It was apparent that there was a marked difference in the 36 to 45 year olds absence rate compared to other groups. An analysis of variance was carried out on the absence rates of each age group. A value of 0.802 was obtained. As the critical value was 3.01, the null hypothesis that there was no difference between the absence levels of each group was accepted.

The full-time workers were absent for 162 days and the mean number of days absent per monitor in this group was 11.6 days. The part-time workers were absent a total of 73 days or a mean of 10.4 per monitor. The economically inactive group had the lowest level of absence, losing only 60 days altogether or an average of 7.5 days per monitor. Again, an analysis of variance was carried out to test the null hypothesis that there was no significant difference between the absence levels of each employment group. The value of 0.435 was below the critical value of 3.39 and again the null hypothesis was accepted and there was no difference between the groups. This indicates that the levels of absence between the differing groups of monitors did not vary. Therefore all types of monitor could be included in a monitoring panel if desired. However, causes of absence could vary between monitors of differing types and therefore, monitors' reports should be designed to ascertain what causes of absence occur and if they differ between different groups. Overall it would appear that the length of time individuals are present in the Vale do not seem to affect their exposure to odour. As an extreme example, a population of commuters or long distance lorry drivers may be just as likely to be exposed to odour as a carer or homemaker. As a consequence, when designing a monitoring panel, the backgrounds of monitors are not important, as they do not seem to influence absence levels and, hence, reporting patterns.

9.6 Odour hedonics

It will be recalled from Chapter 6 that monitors were asked to record the pleasantness and intensity of odours that they reported. They were asked to score pleasantness/ unpleasantness and weak/strong odours on a scale of 1 to 7. A score of 1 referred to an odour that was weak or pleasant and a score of 7 referred to an odour that was strong or unpleasant. The values assigned to landfill odours were examined within the context of the groupings used in Section 7.3, which in turn were based on current knowledge of olfaction. It was hoped to identify relationships between laboratory based olfactometry and odours detected in the field.

When the reports were examined, the following patterns were identified,

- Younger monitors produced a higher percentage of unpleasant odours (68%). Older monitors produced the lowest number of reports with unpleasant odours.
- Older monitors produced the highest number of strong odours.

- Economically inactive monitors produced the highest number of unpleasant odour reports.
- Females produced most reports referring to unpleasant and more intense odours.

However, 64% of landfill odour reports made by males were reported as being pleasant. Closer examination of the data revealed that one monitor, TSK, consistently recorded such odours as pleasant. Although the precise reasons for this are not known, this pattern may have arisen for several reasons. Firstly, the monitor may have been confused as to what score to assign to the odour, using a score of 1 for an unpleasant odour and not 7. It was noted that the report sheet itself had no guidance as to how score odour hedonics. Care had been taken to ensure that monitors knew what they were doing, including instructions given at the meeting, guidance notes and telephone calls prior to and just after the start of monitoring. Despite these precautions, TSK appeared not to understand how to score odour hedonics. This indicates a need to redesign monitoring sheets. Secondly, he may have been an individual with an idiosyncratic sense of smell, who did not find landfill odours unpleasant. Unfortunately, the odour trials prior to monitoring did not include tests for pleasant and unpleasant odours. Thirdly, TSK, and possibly other monitors, may have had genuine difficulty describing hedonic properties. Although TSK may have made a mistake when recording odour hedonics, his cloud and visibility scores were consistent with other monitors. For this reason, his reports were included in the analysis. Finally, it should be noted that the panel was small with only a limited number of people and reports to investigate. One or two individuals with idiosyncratic reports may influence the conclusions that can be drawn, such as TSK's reports influencing the reporting pattern observed amongst males.

As the patterns observed were ambiguous, the detailed results were not included. However, the following observations can be made,

- The results were not the same as those observed in the laboratory.
- Hedonics as an issue in a field-work context needs specially designed research projects, separate from odour monitoring panels such as the one used in this research.

9.7 Results from the post-monitoring questionnaire

As discussed in Chapter 6, it was decided to ask monitors who left the panel after 3 months to complete a post-monitoring questionnaire. Six monitors left the panel after this period and 4 of them completed and returned the questionnaire. The questions asked for information in three main areas. These were firstly, what they thought of the monitoring procedure, secondly, what they thought of the outcome of their results and thirdly, what their response to odours usually was. The results are highlighted in this section.

9.7.1 Opinions on monitoring procedure

The monitors were asked their opinion about different aspects of monitoring. The results to the questions are as follows,

- Found monitoring very easy...1, found monitoring easy...2, found monitoring neither easy or difficult...1
- All monitors felt they had sufficient support from the University

- Problems with monitoring included remembering to monitor (2 monitors), inconvenience (1), unable to identify all odours (1)

9.7.2 Monitors' opinions on their results

The monitors were then asked their opinions on their reporting results.

- 3 monitors stated they reported all odour types at levels that they expected, 1 monitor stated they reported odours less often than they expected, no monitors stated reporting all odours more frequently that they expected
- The monitors stated which specific odours they reported more or less frequently than they expected. The results are shown in Table 9.6,

Odour type	reported more frequently than expected	reported less frequently than expected
local odours	0	2
landfill odours	2	2
brickwork odours	1	3
agricultural odours	0	3

Table 9.6: The specific odours monitors reported more or less than they expected

- 2 of the monitors were surprised by their results, 2 were not
- 3 monitors felt they were more aware of odours after taking part in the project, 1 felt their opinion was unchanged

9.7.3 The monitors' opinions on odour

- 1 monitor had complained about agricultural odours to the council in the past, 3 had not made any complaints about odour
- When they had detected odours, 1 monitor reported closing windows and 1 monitor stated they tried not to breathe deeply
- Monitors reported the following health problems when exposed to odour,

Symptom	Number of monitors reporting symptom
Headache	2
Annoyance	1
Irritability	1
Respiratory problems	1

Table 9.7: Symptoms associated with odour exposure

- Out of four monitors who completed the questionnaire, 3 stated their reason for volunteering for the project was concern about the environment and the local environment in particular. The other monitor stated they wanted to help with the project.

Some significant points were raised by the post-monitoring questionnaire. Firstly, the monitoring procedure was generally straightforward. This indicates that future panels could be run along these lines. Secondly, three of the four monitors completing the questionnaire said they were more conscious of odours after monitoring. This suggests that once used in a panel, individuals should not be used again. Finally, the motivation for most of these monitors was concern about the environment. Whether or not their reporting patterns were influenced by these concerns is not clear. But this does suggest that more detailed questions on pre-monitoring questionnaire on environmental issues and analysis of reporting patterns based on these questions may be necessary.

9.8 Links with the environment: comparing monitors' reports with wind speed and direction

It was decided to check reports against the wind direction and wind speed recorded at the time when the report was made. The individual monitors will be referred to by their code names, as elsewhere in the thesis.

It was also decided to compare the landfill odour reports made by each monitor with the wind direction and speed recorded at or near to the time of the report at local weather stations. It is known that meteorological conditions are important in the release and dispersion of atmospheric pollutants, including landfill odour (see Section 4.4). Movement of a pollution plume is determined by three variables, namely wind direction, wind speed and atmospheric stability. Wind direction determines dispersion of the plume, that is where it travels and therefore which areas will be affected. Wind speed and stability determine concentration of gaseous pollutants, as they influence atmospheric turbulence levels (Boubel et al 1994). In other words how high or low concentrations are off-site. So, for example, high stability and low wind speed result in high concentrations close to a source. For example, when the wind speed is lower, plume dilution is reduced as eddies generated by turbulence are smaller, which in turn leads to greater potential impact. Nkemdrim (1988) states how the threshold for effective dispersion of pollutants is around $3ms^{-1}$. Low stability and/or high wind speeds indicate greater dispersion and dilution resulting in low concentrations over a wide area. It was hoped to identify an association between the wind's properties and monitors' reports, namely that the wind speed and direction were slow enough and in the correct direction for the landfill to be the source of the odour detected.

Data from local automated meteorological stations at Bedford were used for this activity. Stability measurements are not recorded at automated stations therefore wind speed and direction were used. As with the exercise of assessing the quality of monitors' data using cloud and visibility categories, it was hoped to identify general patterns of reports and their relationship with wind direction and speed.

Several steps were undertaken in this comparison. Firstly, the compass bearings from each landfill to the monitors' locations were estimated. It was decided to use a range rather than one specific direction. So, for example, monitor VHB at Brogborough was identified as being within 180 to 200° south of Brogborough landfill and 220 to 230° southwest of Lfield. Therefore if the wind was blowing from the north, at approximately 0°, the wind would blow across Brogborough landfill to the VHB's location. Therefore if there were odour causing compounds being released by the landfill the plume would be transported to the monitor also. This is illustrated in the sketch map, Figure 9.1.

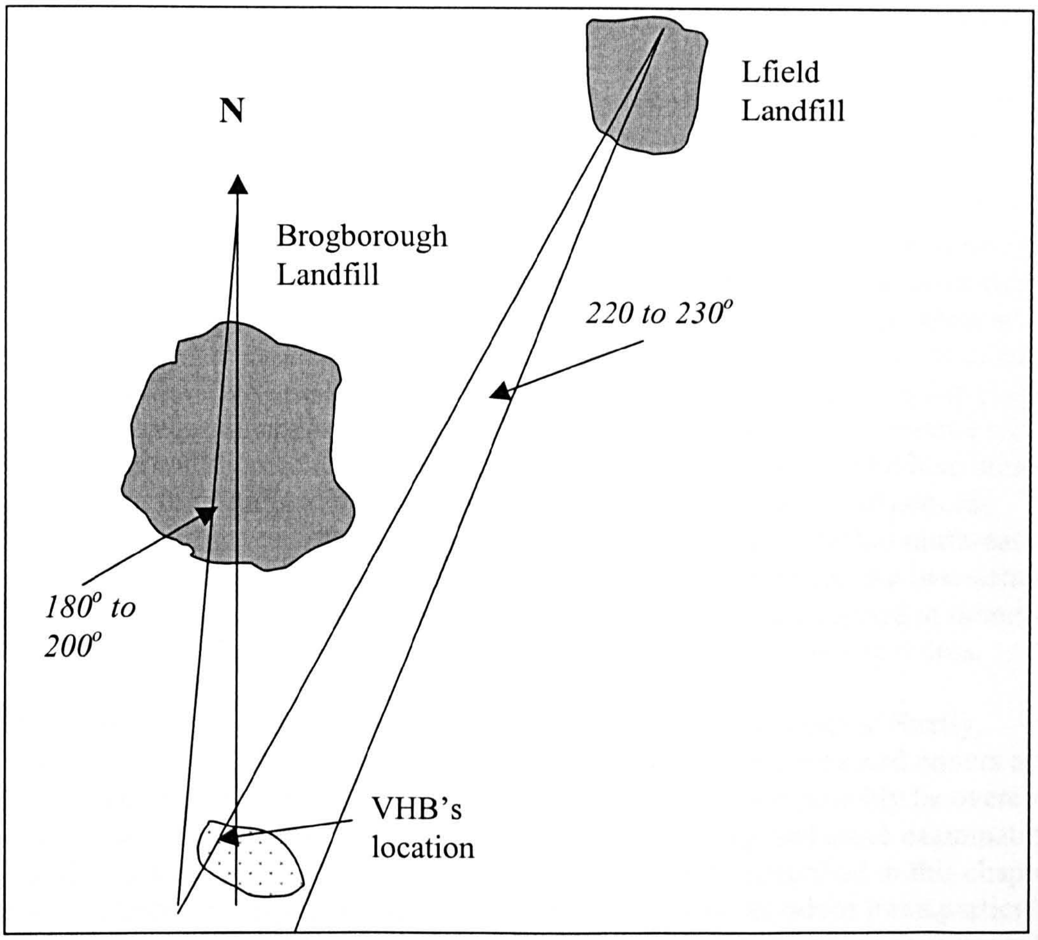


Figure 9.1: How the orientation of landfills and monitors were estimated

It was decided to use reports that were made at or close to the monitors' homes, so that the monitors' orientation with respect to the landfill sites could be identified. This involved using 98 of the 111 landfill odour reports recorded during the monitoring period. Finally, the dates and times of each monitor's landfill odour reports were compared to the wind speed and direction recorded at or near that time. The monitor reports were again extracted from the database, using the query facility. The details of date, time, monitor location and landfill odour report were extracted. They were then compared by hand with wind parameters extracted from meteorological data. The results are summarised below.

- There were 19 reports where the wind direction was in the correct direction for a monitor to detect an odour.

- 92 reports were made where the wind speed was between 0-9m/s^{-1}, 6 reports were made when the wind speed exceeded this speed. The peak wind speed for reports was 2m/s^{-1} (28 reports)

- Examination of the 4 complaints revealed that 1 complaint was made when the wind was in the wrong direction and 3 complaints were made when the wind was blowing in the correct direction. The wind speed for all complaints was below 9m/s^{-1}.

It would appear that the majority of reports (77 reports or 79%) were made when the wind was not blowing in the right direction for a monitor to detect odour. This was a disappointing result, but there were two sources of potential error that may have caused this discrepancy. These were the meteorological data and the monitors' reports.

The meteorological data were not local to the Marston Vale, but were collected in Bedford. As Stern (1968) states, extrapolating data from one place to another can be difficult as weather patterns can vary even over small distances. This problem is compounded by the data being collected in a built up area and being used to assess reports collected in a rural one. Stern (ibid.) describes how built up areas can produce different temperature and wind profiles compared to rural ones. These factors may result in the development of differing localised weather patterns in a built up area and the rural area surrounding it. Comparison was made between the wind patterns recorded at Cranfield airfield and Wyton airfield, approximately 60 km north-east of Cranfield. Both wind direction and speed varied frequently between the two stations. This problem could be overcome by using meteorological data collected at monitors' locations, overcoming the problems of using data collected in a different area.

The second source of error related to monitors' behaviour and reports. Firstly, monitors may have had personal "agendas", whereby they would record odours as they pleased and not as they smelled them. This problem could possibly be overcome by more rigorous screening of volunteers prior to monitoring and close examination of reports as they were submitted, possibly using strategies described in this chapter. Secondly, monitors may make mistakes. They may believe an odour has a particular source, such as the landfill, when in fact the odour arises from another source. Or they may be ill with a cold that may distort the odour as they smell it. Recording any illnesses at the time of monitoring should be encouraged. To overcome the problem of mistaken identification, training should perhaps be considered, despite the problems it may entail (see 6.4.3).

An interesting pattern emerged when wind speeds were compared to odour reports. In the majority of cases, 92 reports or 95%, the wind speed was at or below $9m/s^{-1}$. All complaints were made when wind speed was lower than $9m/s^{-1}$. This may indicate that wind speed may be an important factor in odour events, perhaps as much as wind direction. As referred to above, wind speed can be critical in dilution and dispersion of pollutant plumes. Oke states that differing topographies and meteorological conditions lead to development of local wind systems and therefore there is a great need for knowledge of local climates. He goes on to say, however, "the complexity of the wind field often rules out any detailed understanding of dispersion".

9.9 Summary of Chapter 9

Examination of the cloud and visibility categories used by monitors showed that usually there was some consensus on the categories used. When monitors did report categories that were markedly different to others, there was agreement with at least one other monitor. For example, it was noted that monitors NCL and VHB had recorded category 8 on the 25 and 26 April, when other monitors had not used such high categories. However, they both lived at the southern end of the Vale, which may have been experiencing different weather conditions to the rest of the Vale. Unfortunately, the weather data would not reveal such differences on a localised scale. One monitor, SWKH, did record categories that were different to other monitors indicating that she may not have been making consistent reports.

The reports and reporting intensities for long-term monitors were generally lower than those produced by new monitors. It is suspected that monitors should not be retained on panels for too long as they appear to lose motivation to report odours. How long they should be retained is not clear, as the long-term monitors had all been monitoring for three years. The reporting patterns of new monitors fell over three months, which may indicate that fatigue may set in over a short period of time. This suggests that reporting patterns should be checked regularly to identify monitors who are experiencing monitoring fatigue.

Examination of the levels of absence amongst monitors appeared to show that absence as such was not markedly different between monitor groups and did not appear to affect the results. This suggests that absence is not an important factor to be considered in panel design.

There were four occasions when reports and complaints to the landfill operator were made together (66% of complaints). There were two complaints made when there were no reports recorded by monitors. If anything, this pattern reflected what had been observed from historical complaints and reports data examined in Section 8.2.

The results from the questions related to odour hedonics indicated that monitors could be confused when recording their reports. Monitor TSK appeared to have scored odours wrongly when reporting odour pleasantness and intensity. This would suggest that the reporting sheets should not only have scales for monitors to use but also descriptions to avoid confusion.

The post-monitoring questionnaire revealed that concern for the environment was a motivating factor for individuals to volunteer as monitors. One monitor had complained to the local authority in the past, but this was agricultural, not landfill odour. Three monitors stated that they had become more aware of odours as a result of monitoring. This would suggest that it is individuals who are concerned about their environment that will volunteer and once used in an odour study, they should not be used again as there is the possibility they will be more aware of odours. This may lead to their over-reporting odours, which would be unsatisfactory, as it is the response of the general population that is sought.

Examination of wind direction blowing at or around the time of monitors' reports revealed that there were few occasions where the wind was blowing in the right direction for landfill odours to be "delivered" to monitors (19 occasions out of 98 reports). However, as noted earlier, there were difficulties associated with this exercise. Two sources of error associated with the meteorological data used and monitors' reports were identified. These sources of error may have led to the apparent discrepancy between reports and wind speed and direction. Suggestions for overcoming these sources of error, such as use of local meteorological data and more rigorous screening of volunteers were made. There did appear to be an association with wind speed, with the majority of reports being made when wind speed were below $9ms^{-1}$. It has been suggested that low wind speeds result in limited dilution of an odour plume and therefore will be associated with odour pollution events.

As stated at the outset of this chapter, the above activities related to the assessment of the reliability of monitors' reports. When using monitoring panels such procedures should be undertaken routinely for several reasons. Firstly, to ensure that the reports are at a consistent level. Secondly, to ascertain that individual monitors are monitoring satisfactorily and not experiencing fatigue. When this problem is identified, then the monitor should be removed from the panel, and, as suggested by the post-monitoring questionnaire, not be asked to monitor again. Thirdly, to identify monitors who may not be reliable reporters of odour. The activities reviewed above should be undertaken as a matter of course when designing and operating a monitoring panel, to ascertain that reports are as valid as possible. Only by ensuring the quality of monitoring panel reports, can the development of a framework and possibly a future model be undertaken with some confidence.

Chapter 10

The development of a framework for assessing population response to odour

10.1 Introduction

This thesis is located in the cost benefit framework developed by Longhurst and Seaton (1999) discussed in Section 1.2 and illustrated in Figure 1.2. The specific area of interest identified in Section 1.2 was identified as the consequences of the "delivery" of odour to specific areas. It will be recalled that objective 1 in Section 1.6 stated that an attempt would be made to produce a framework for assessing population response that would operate within this area of odour impact. It would operate alongside long-standing methods of odour impact assessment or prediction, such as olfactometry testing, laboratory-based methods such as GC-MS and dispersion modelling. It could be used in a complimentary fashion with these techniques in an interdisciplinary method of odour assessment.

There was a great deal of variability identified in the reporting patterns of individual members of the monitoring panel. However, when attempting to assess the response of a population to odour pollution, it is simplest to assess response by particular groupings, such as age or health. These attributes are thought to affect olfactory ability and therefore could be given different weightings as to how much they affect detection levels. This has already been carried out in Chapter 7, when reporting intensities were calculated both for individual monitors and groups. Such reporting intensities could be produced for assessing the impact of odour pollution across an area such as the Marston Vale. This chapter discusses how this could be done by use of a population response framework and provides examples. It should be noted at the outset of this chapter that there are two problems associated with this research activity. The first problem relates to the results from the attribute groupings in the panel used in this research. The results from the panel appeared to conflict with what is known of olfactory ability from other research. As a result of the literature findings the groupings will still be used in the development of the model, but with reservations (see 7.3.1 and Chapter 11). The second problem relates to olfactory ability in general. It appeared from examination of the reporting intensities of individual monitors that there is a huge amount of variability in detection of odours. There were no overall patterns identified of individual attributes that appear to influence this variability most. Rather, the ability to detect odours appears to be a product of multiple attributes acting in tandem. It should be noted, however, that the groupings themselves are artificial. It will be recalled from Section 7.2, that there was substantial variation of detection of odour, even amongst individuals with the same attributes. For example, it will be recalled from 7.2.3 that amongst 18 to 35 year olds, landfill odour reporting intensities varied from 0.0 (monitors SJS and BLWG) to 0.209 (monitor NHTC). This is a feature that should be addressed by further research, probably through the use of panels designed as research instruments to ascertain the interaction of attributes, rather than as monitoring panels per se. This would assist with the development of a model, not as in the case of this research, a response framework. The variability of response and its consequences for attempts to develop a framework are reviewed in Chapter 11.

In Section 10.2 how reporting intensity values for particular types of individual could be calculated from the available data is discussed and examples shown. In other words a means of estimating or predicting an individual's or a group of individuals with similar attributes exposure to odour is developed. It should be stressed that the reporting intensities calculated are predictions or estimates and are not calculated values such as those in Chapter 7. In principle such a framework would enable interested parties, such as regulatory bodies or odour source operators to estimate exposure levels and possible levels of nuisance within a population. Section 10.3 explains how the population response framework could be used. In Section 10.4, the limitations and difficulties encountered with using the framework are reviewed. These include the panel design and data produced and the nature of the 1991 Census data.

10.2 Development of a framework to assess response to odour

In order to produce a framework to assess response, the reporting intensity values obtained from a monitoring panel are used in conjunction with Census data. Below are worked examples of how reporting intensities, first referred to in Section 7.2, can be used to estimate or predict individuals and groups or settlements most likely or least likely to be affected by odour pollution. The first example demonstrates how reporting intensities can be used to assess odour impact at settlements.

To obtain the reporting intensities for each settlement in the Marston Vale, the following steps were taken.

- The total number of reports of all odours and landfill odours made by all the monitors were counted.
- The total number of monitoring days recorded by the monitors were also counted
- The number of reports was then divided by the number of monitoring days to obtain the reporting intensity values for all the settlements.

So:

$$\frac{\text{Number of reports}}{\text{Number of monitoring days}} = \text{Reporting Intensity}$$

An example is shown below:

Example 1: Reporting Intensities at different settlements
The monitors at Cranfield made 121 reports of odour, including 21 reports of landfill odour. They monitored on 356 days. In order to obtain the reporting intensity for all odours, the total number of reports is divided by the number of days,

All odours reporting intensity value: $\frac{121}{356} = 0.34$

Landfill odour reporting intensity value: $\frac{21}{356} = 0.06$

The reporting intensity values for all odours and landfill odours for the settlements are shown in Table 10.1.

Settlement	Reporting days	Total all odour reports	Total landfill odour reports	All odour reporting intensity	Landfill odour reporting intensity
Brogborough	**142**	**36**	**7**	**0.25**	**0.05**
Cranfield	**356**	**121**	**22**	**0.34**	**0.06**
Kempston	**325**	**72**	**12**	**0.22**	**0.04**
Kempston H.	**231**	**122**	**5**	**0.53**	**0.02**
Lidlington	**254**	**50**	**7**	**0.20**	**0.03**
Marston M.	**88**	**78**	**16**	**0.89**	**0.18**
Stewartby	**406**	**177**	**30**	**0.44**	**0.07**
Wootton	**339**	**66**	**8**	**0.20**	**0.02**
Wootton G.	**220**	**74**	**4**	**0.34**	**0.02**

Table 10.1: Reporting intensity values for settlements in the Marston Vale

The highest reporting intensity values for all odours were at Marston Moretaine, Kempston Hardwick and Stewartby. The lowest values were produced at Lidlington and Wootton. The highest landfill odour reporting intensity values were produced at Marston, Stewartby and Cranfield. This is fairly consistent with the pattern of complaints discussed in Chapter 5, where complaints were concentrated at Cranfield and Stewartby, although complaints did not arise at Marston or other settlements. During the monitoring period, complaints were produced at the following locations. First, Rectory Farm (approximately 1km northwest of Brogborough landfill) and, second Wood End (roughly equidistant between Marston and Brogborough landfill and approximately 1km northeast of Brogborough landfill). Other complaints were made at Marston itself. The lowest landfill odour reporting intensity values were produced at Wootton Green and Kempston Hardwick.

Using the same method, the settlements can be divided into groups to identify if the location of the settlements influences reporting intensity. For example, they were divided into settlements in the west of the vale (Lidlington, Brogborough, Cranfield and Wootton Green) and the east (Marston, Stewartby, Wootton, Kempston Hardwick and Kempston). The reporting intensities were calculated for each group and are shown below in Table 10.2.

	Western Marston Vale	Eastern Marston Vale
Reporting intensity - all odours	**0.29**	**0.36**
Reporting intensity - landfill odours	**0.04**	**0.05**

Table 10.2: Reporting Intensities for western and eastern settlements

It can be seen that the reporting intensities for all odours are higher for settlements in the east. Additionally, landfill odour reporting intensities are similar for both areas, with the eastern settlements having a slightly higher value. The higher values for the eastern settlements are not unexpected as the prevailing wind blows from the south-west to the north-east and the settlements in the east are downwind of the landfills and brickworks.

Another approach to using this impact assessment method is to group the settlements by distance from the nearest landfill site. There were four settlements within approximately 2km of a landfill, Cranfield, Kempston Hardwick, Stewartby and Wootton Green. There were four settlements within 3km of a landfill, Brogborough, Lidlington, Marston Moretaine and Wootton. The reporting intensities for each group are shown in Table 10.3.

The all odour reporting intensities for settlements closest to the landfills were higher than those further away. The landfill odour reporting intensities were the same. This suggests that distance has no influence on landfill odour impact. However, there is the possibility that monitors were confused about the odour source.

	Settlements approx. 2km from a landfill	Settlements approx. 3km from a landfill
All odour reporting intensity	**0.39**	**0.29**
Landfill odour reporting intensity	**0.05**	**0.05**

Table 10.3: Influence of distance from landfill sites on reporting intensities

The analysis facilitates comparisons between groups where the influence of a single component, such as gender or age, has to be identified. This was undertaken in Chapter 7, where reporting intensities were calculated for such groups. This procedure can also be used to examine the influence of more than one attribute on reporting intensity. The reporting intensities for males and females, within each settlement can also be obtained. (This is assuming that the literature on gender and olfactory ability are correct, and that gender can influence the sense of smell. As mentioned elsewhere further research should be conducted to identify if this is so.) Below is an example of reporting intensities calculated for males and females at two settlements in the Marston Vale. The settlements selected for this example are Wootton and Stewartby. The population sizes for each settlement are 3772 and 985 respectively. The numbers of males and females for each settlement are shown below (the population sizes and numbers of males and females were obtained from 1991 Population Census data).

Example 2: Reporting intensities by location and gender

	Stewartby	Wootton
Population size:	985	3772
Number of females:	513	1836
All odour reporting intensity:	0.54	0.16
Landfill reporting intensity:	0.05	0.04

To calculate the total odour reporting intensity value for all odours for females at Stewartby, the reporting intensity of female monitors is calculated and multiplied by the number of females living at Stewartby. This value is then divided by the total

number of people living at the settlement to obtain a weighted average value for a reporting intensity value for females living at Stewartby.
Reporting Intensity value for all odours for females at Stewartby:

$$0.54 \times 513 = \frac{277.02}{985} = 0.28$$

Similarly the reporting intensity value for landfill odours for females at Wootton is calculated the same way, as shown below,

$$0.01 \times 1836 = \frac{18.36}{3772} = 0.005$$

The values for females and males at all the settlements were calculated as above and are shown in Table 10.4. There were some settlements, Brogborough, Kempston Hardwick and Marston Moretaine where no males were present to produce reporting intensities. When this occurs, then the reporting intensity for all males on the panel could be substituted to provide an estimate of the impact of odour on such settlements.

Settlement	Male all odour reporting intensity	Male landfill odour reporting intensity	Female all odour reporting intensity	Female landfill odour reporting intensity
Brogborough	**0.15***	**0.03***	**0.14**	**0.02**
Cranfield	**0.07**	**0.01**	**0.19**	**0.03**
Kempston	§	§	§	§
Kempston H.	§	§	§	§
Lidlington	**0.16**	**0.01**	**0.07**	**0.01**
Marston M.	**0.16***	**0.03***	**0.45**	**0.09**
Stewartby	**0.15**	**0.05**	**0.28**	**0.03**
Wootton	**0.11**	**0.02**	**0.08**	**0.005**
Wootton G.	§	§	§	§

* Estimates based on general male reporting intensities (no male monitors at this location)
§ No population sizes available for this settlement

Table 10.4: Reporting intensity values for males and females at each location

The estimated or predicted values in the table suggest that the impact of odour, both landfill and in general, do vary at different settlements across the Marston Vale and between males and females at these settlements. Conclusions regarding odour pollution can be drawn from comparing estimated odour intensity values. For example, higher reporting intensity values were calculated for both males and females at Stewartby. Females produced higher reporting intensity values for all odours than males (0.28 to 0.15 respectively). However, landfill odour reporting intensity values were similar for both groups (0.03 and 0.05), which suggests that the impact of landfill odour on both groups is also similar.

Once the details of the monitors' reports are to hand it is a fairly straightforward process to calculate reporting intensity values for different groups of people, such as males and females above. Reporting intensity values can be calculated for groups with more attributes, such as males of different age groups or females aged 18 to 35 who work full-time. Examples of such calculations are presented in examples 3 and 4.

Example 3: Reporting intensity by gender and employment pattern

The reporting intensities for males and females who worked full-time or part-time or who were economically inactive were calculated. This was done by taking all monitors in each category and, using the method discussed above, obtaining the reporting intensity value for that category. For example, the reporting intensity value for male monitors who were economically inactive was calculated as follows,

There were three monitors in this group - KBS, PCW and JSW.
Total number of days = 83 + 86 + 91 = 260
Total all odour reports = 33 + 31 + 11 = 75
Total landfill odour reports = 14 + 5 + 1 = 20

Reporting intensity for all odours: $\frac{75}{260} = 0.29$

Reporting intensity for landfill odours: $\frac{20}{260} = 0.08$

Table 10.5 shows reporting intensities for all employment groups by gender.

	Full-time	Part-time	Economically inactive
Female all odour intensity	**0.48**	**0.16**	**0.48**
Female landfill intensity	**0.04**	**0.01**	**0.11**
Male all odour intensity	**0.31**	*	**0.29**
Male landfill intensity	**0.04**	*	**0.08**

* No males on the monitoring panel worked part-time

Table 10.5: Reporting intensities based on gender and employment group

Such calculations show how employment pattern and gender influence reporting intensity values. Comparisons are possible between females with differing working patterns and between males and females with differing working patterns. It can be stated that whilst females working full-time and those who were economically inactive produced the same reporting intensity values for all odours (0.48). However economically inactive females produced a higher reporting intensity for landfill odours compared to females in the other occupation groups (0.11 compared to 0.04 for full-time workers and 0.01 for part-time workers). Males produced lower reporting intensity values for both types of odour for both employment categories, other than landfill odour intensity for full-time workers where the value was the same for both males and females (0.04). These values can be used in conjunction with census data as in example 2. So if a comparison between males and females with different employment backgrounds at Brogborough were required, they could be calculated.

Numbers of females in each employment category living at Brogborough:
Full-time employment: 58

Part-time employment: 27
Economically inactive: 32
Number of males in each employment category living at Brogborough:
Full-time employment: 86
Part-time employment: 0
Economically inactive: 13

Calculating full-time females reporting intensity value for all odours

$$58 \times 0.48 = \frac{27.84}{322} = 0.09$$

If the calculations are repeated for the other groups, the following results for females at Brogborough are obtained,

	Full-time employment	Part-time employment	Economically inactive
Female all odour intensity	**0.09**	**0.01**	**0.05**
Female landfill odour intensity	**0.01**	**0.00**	**0.01**
Male all odour intensity	**0.08**	*	**0.01**
Male landfill odour intensity	**0.01**	*	**0.00**

* no males living at Brogborough work part-time

Table 10.6: Reporting Intensity values for females in different employment categories at Brogborough

The reporting intensity values indicate both males and females that work full-time produce higher reporting intensity values than any other group at Brogborough for both all odours and landfill odours. Interestingly, economically inactive males produce lower reporting intensity values than females.

This example illustrates a problem with the monitoring panel in the form used for this research and that is there were categories where no monitors were available, such as males who worked part-time. This led to categories where reporting intensities could not be calculated. This is discussed further in Section 10.4.

Example 4: Reporting intensity by gender, employment pattern and age
In a similar fashion to example 3, it is possible to calculate reporting intensities for three attributes, such as gender, employment and age. In this example, reporting intensity values are shown for each group and then are used to calculate reporting intensities for these groups at Brogborough. It should be noted that, as with example 3, there are missing values due to the panel not containing monitors with a particular combination of attributes. For example, there were no monitors who were male aged between 18 to 35 who were economically inactive. Below is an example of how the reporting intensity for all odours for economically inactive females aged between 18 and 35 was calculated:

Two females fell into this category - VHB and NHTC
Total number of monitoring days: $85 + 91 = 176$
Number of all odour reports: $35 + 69 = 104$
Reporting intensity for all odours: $\frac{104}{176} = 0.59$

Reporting intensities calculated for all groups where possible are shown in Table 10.7.

		Males			Females	
	Full-time	**Part-time**	**Econom. Inactive**	**Full-time**	**Part-time**	**Econom. Inactive**
18-35 all odour	**0.25**	*	*	**0.6**	**0.08**	**0.59**
landfill odour	**0.18**	*	*	**0.06**	**0.00**	**0.15**
36-45 all odour	**0.65**	*	*	**0.57**	**0.14**	*
landfill odour	**0.02**	*	*	**0.01**	**0.00**	*
46-55 all odour	**0.26**	*	**0.12**	**0.38**	**0.27**	**0.09**
landfill odour	**0.06**	*	**0.03**	**0.03**	**0.03**	**0.03**
56+ all odour	**0.13**	*	**0.38**	*	*	**0.91**
landfill odour	**0.02**	*	**0.11**	*	*	**0.18**

* values could not be calculated as no monitors fell into this category

Table 10.7: Reporting intensity values by age, gender and employment category

The estimated values from Table 10.7 are then used to calculate reporting intensities for each monitor group. For example, the reporting intensity for all odours for females aged 18 to 35 living at Brogborough who work full-time,
There are 23 females in this category.

$$23 \times 0.6 = \frac{13.8}{322} = 0.04$$

The estimated reporting intensity values for each category were calculated and are shown in Table 10.8.

If the population structure at Brogborough was different then this would affect the reporting intensity values. If there were twice as many women in the 18 to 35 age group who worked full-time (46 instead of 23), the reporting intensity for the group would also double to 0.09, as shown below,

$$46 \times 0.6 = \frac{27.6}{322} = 0.0857 = 0.09$$

		Females		Males	
	Full-time	Part-time	Econom. Inactive	Full-time	Econom. Inactive
18-35 all odours	**0.04**	**0.00**	**0.03**	**0.03**	*
landfill odour	**0.00**	**0.00**	**0.01**	**0.02**	*
36-45 all odours	**0.02**	**0.00**	**0.00**	**0.05**	*
landfill odour	**0.00**	**0.00**	*	**0.00**	*
46-55 all odours	**0.02**	**0.00**	**0.00**	**0.01**	**0.00**
landfill odour	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
56+ all odours	**0.00**	**0.00**	**0.03**	**0.00**	**0.00**
landfill odour	***0.00**	**0.00**	**0.01**	**0.00**	**0.00**

* reporting intensities could not be calculated for this category

Table 10.8: Reporting intensities based on gender, age and employment category at Brogborough

This is only one example of how the framework can be used to assess impact on changes to population numbers. It facilitates comparisons of odour impact between different settlements and between different types of people found at those settlements. Highly specific groups can be selected, for example female aged over 56, who are retired, who smoke and who have health problems and their reporting intensities calculated. It is also sufficiently flexible to take into account population changes as in the last example shown above.

10.3 Use of the proposed population response framework

It will be recalled from Section 1.2 that this research is located within the wider sphere of landfill management, impact on communities and the concerns of regulatory bodies. This sphere also contains aspects such as landfill management, waste decomposition and odour emission, dispersion and transformation and evaluation of loss of amenity. One of the objectives of the research, objective 1, proposed the development of a population response framework. The response framework was also visualised as being used at part of an interdisciplinary method of odour pollution assessment where these aspects are assessed together. The framework would be introduced through the data derived from a monitoring panel, such as the one used in this research. On the basis of the results, estimated reporting intensities could be produced for individuals at specific locations and with particular attributes or combinations of attributes. Calculations of estimated reporting intensities for different settlements were carried out in Section 10.2 and examples provided. For example, Table 10.1 shows reporting intensities for the nine settlements where monitors were located. It can be seen that Marston Moretaine produced the highest reporting intensity for overall odours and for landfill odour. Stewartby also produced high intensities for both odour types. This would suggest to a landfill operator or a local authority that this is where there is likely to be the greatest impact of landfill odours. The landfill operator or authority could use dispersion models to identify if these areas would indeed experience greater levels of odour pollution and how frequently.

Measurement of emissions of odour at source could be attempted and these data, along with local meteorological data could be used in conjunction with the framework. Data from the source could be used in a dispersion model. The dispersion model would provide estimates of areas likely to be adversely affected by odour pollution, perhaps also the odour concentrations involved, and the numbers of hours odours would be present for example over the course of six months or a year. A monitoring panel would provide detail on the intensity of odours detected away from the site and the times and duration of odour events. As mentioned earlier, a dispersion model will provide predictions of the overall length of time odours may be present, but a panel could provide information on times of day when odours are detected and possibly the duration of odour events. The panel would be providing information at the point of odour delivery that could compliment data derived from the source. Operators at the landfill could take into account wind direction and speed when undertaking activities known to be likely to lead to odour release, such as trench excavation, or realise the importance of quickly rectifying problems that may lead to odour release, such as flares going out. They could also identify times of day when detection is most likely and, where possible avoid carrying out operations that may lead to odours being released and detected. If they could identify sensitive areas, then they could manage their operations sensitively also. The use of monitoring panels in conjunction with physical measurement and modelling would result in an interdisciplinary method being implemented.

As a population changes, for example if new housing development took place and a population expanded, the framework could estimate level of detection and impact. It could also take into account changes in population structure, such as an influx of younger or older people. As shown in example 4 above, it was also shown how the framework could take into account changes to the structure of a population, for example an influx of females to Brogborough was used. The example indicated how if the number of females doubled how the reporting intensity for that group would double also. It may be possible for an operator or authority wished to use the framework derived in one area in another. It would be possible to take population data from the latest census in tandem with reporting intensities calculated elsewhere, and use this information to estimate likely reporting intensities of different members of the population and by doing this identify settlements with the greater or lesser impacts.

It became apparent during the research that the response framework could also be put to a second use. The model would provide estimates or predictions of the impact of odour on individuals and groups of people found within the populations of different settlements. These reporting intensities could also be used to compare the experience of individuals and groups against other groups. This ability to compare the differences in detection levels could be useful in attempting to link studies into differences in olfactory ability to the "real world". This was also demonstrated in Section 10.2.

For example, examining the reporting intensities obtained for males and females within specific employment groups (Table 10.5), it can be seen that females within the economically inactive group produced a reporting intensity of 0.48 and males 0.29. It can be predicted that economically inactive females in the Marston Vale will experience higher levels of detecting odour than their male counterparts. This suggests that they may be more sensitive to odours or find themselves in situations where they are more likely to detect odours. Researchers with an interest in olfactory ability or exposure to pollution could use panels and reporting intensities to gain greater insight into how olfactory ability and lifestyle may influence exposure and detection levels.

10.4 Difficulties encountered with developing the response framework

The difficulties encountered when using the framework fell into two categories. Firstly, those associated with the nature of the Census data, and secondly, those associated with the structure of the monitor panel and the intensity values produced.

The Census data provided information on population sizes of settlements, the numbers of males and females and numbers of individuals in different employment categories. The data did not provide information on the numbers of smokers or individuals with health problems. Health problems had been identified in the panel as affecting reporting intensity. Smoking had produced reporting intensity values at variance with the literature. However as stated in Section 10.1, it was decided to continue using groups with unclear results in order to give a feel for how the framework was developed and what kind of predicted/estimated values would be produced. It was not possible to generate estimates of reporting intensities for smoking/non-smoking and healthy/non-healthy groups. No examples using these factors could be calculated. Also, separate data for Wootton Green, Kempston Hardwick and the southern part of Kempston (which was selected for the panel) were not available. The data for all of Kempston were available, but this would have entailed estimating the population size of the area covered by the panel, which was not satisfactory. Similarly, Census data for the other two settlements fell into the "Kempston Rural" category, which would, again, have entailed estimating population sizes.

Other difficulties arose with the structure of the monitor panel. The panel was smaller than desirable and the numbers of monitors at some settlements were too small. This was particularly the case with Marston Moretaine, where there was only one monitor present. It was unfortunate that this was the case as Marston was at a potentially significant location, being approximately 2.5km equidistant from the two landfill sites and being approximately 2.5km away from the brickworks. The monitor, MHMM that was present at this settlement produced a substantial number of reports. However, it was not clear if this exceptional, her being sensitive to odour or a reflection of the normal level of odours at Marston. Similarly, having only female monitors at Brogborough resulted in it not being possible to generate estimated reporting intensities for males.

Similarly, the small size of the monitoring panel produced comparatively few reports to work with (111 landfill odour reports over 3 months). The monitors were unevenly spread across the Vale and the panel structure was such that some groups were underrepresented, for example males, individuals with health problems and older individuals. In order for a panel to be representative of a population and for it to produce sufficient reports, it would have to be larger with all the problems of management and data analysis it would entail. Due to these limitations, the development of the model was not wholly successful. However the research activity did illustrate how a response framework could be developed.

Chapter 11

Assessment of Community Response to odour:

Conclusions, recommendations and contribution to knowledge

11.1 Introduction

The research process was focused on producing a means of assessing the population response to or its "receptivity" to odour pollution (Section 1.2). It will be remembered that this concept was utilised by Longhurst and Seaton (1999) in their paper on engineering issues associated with the landfill site and communities affected by landfill odour. The research question raised in Section 1.6 was

"To what extent do physiological, lifestyle and locational factors influence exposure and response to landfill odour?"

The overall research objectives related to this question were,

- Objective 1: To identify attributes influencing the exposure and response to odour within a community. These attributes could then be included in a population response framework that could be used to identify communities and members of communities at more or less risk of exposure and response to odour. Then go on to indicate how this framework could be used in the assessment and measurement process.

This objective was based on the next two objectives,

- Objective 2: To measure and demonstrate the variability of response within a population exposed to odour. It will be shown this variability arises from several key components, namely physiology, psychology and lifestyle. These components were shown to be influential in the individual's experience of odour.
- Objective 3: To measure and demonstrate how temporal and spatial factors also contribute to the exposure of individuals to odour pollution.

Objectives 2 and 3 would facilitate the development of the framework identified in objective 1. The objectives generated questions pertaining to the key components (summarised in Figure 4.1) and the community and individual experience of odour (see Section 4.2). These were as follows:

- How do personal factors, such as age or health affect the exposure and response levels of odour an individual can experience?
- How does an individual's lifestyle and behaviour influence their exposure and response to odour?

- How do temporal and spatial factors influence exposure and response to odour?

These questions drove the analysis of data from the pilot monitoring panel and the odour-monitoring tree. On the basis of the analysis and the tree, the questions were further broken down in Table 5.4 in Section 5.2, reproduced below in Table 11.1.

Result from pilot study and data analysis	Question raised
Settlements affected by different odour types	**1. Does this arise due to environmental factors, such as location? (Chapters 3 and 4) (see Chapter 8)** **2. Is it a result of the type of monitor and their lifestyle found at each location? (Chapter 2) (see Chapters 7 and 8)**
Peak reporting times	**3. Does this arise due to operational factors on site? (Chapter 4)** **4. Does this arise due to monitor lifestyle? (Chapter 2) (see Chapter 7)**
Variation in number of days reports were made and the number of reports	**5. Is this due to monitor behaviour? For example work patterns, length of time spent outside (Chapter 2) (see Chapter7)**
Variation in reports made by different age groups	**6. Is this due to the locations where different monitors live? (Chapters 3 and 4) (see Chapter 8)** **7. Is it due to age alone? (Chapter 2) (see Chapter7)** **8. Is there interplay of other factors, for example age and location, lifestyle (Chapters 2 and 3) (see Chapter7)**
Variations in reports made by gender	**9. As with results from age groups, is the result seen the product of gender?(Chapter 2) (see Chapter 7)** **10. Is it the result of other factors, such as location, age? (Chapter 2) (see Chapters 7 and 8)**
Possible variation in other groups such as smokers and non-smokers	**11. Due to the different report patterns due to age and gender, was there other attributes such as health which may influence exposure levels? (Chapter 2) (see Chapter 7)**

Table 11.1: Summary of questions raised from analysis of pilot study data

It can be seen that these detailed questions identify spatial and temporal factors and personal attributes that affect odour detection and link directly to the research objectives. The panel was introduced in an attempt to answer these questions. It other purpose was to serve as a source of information that could form the basis of assessing population response. Results obtained from the odour-monitoring panel were used to calculate reporting intensity values (Chapters 7 and 8). These values were obtained by normalising the number of reports of odour against the number of days each monitor were active. These values facilitated comparisons of response levels between different monitors or types of settlement. The concept of reporting intensity was then used as the basis of the population response framework.

11.2 The monitoring system

Drawing together information from Chapters 7, 8 and 9, it is possible to review the performance of the panel used in this research and its effectiveness and limitations. The panel demonstrated the variation in exposure on the level of the individual, groups and communities.

The design of the monitoring panel was appropriate for demonstrating the variability of response to odour across a population, which arises from various personal attributes, such as health, occupation and location (Objectives 1 and 2). The panel facilitated the production of a population response model (Objective 3).

The research highlighted how an odour monitoring panel could be designed and constructed, and how, using the results from such a panel could be used to generate a population response framework. The results are summarised below. The design and management of such a panel formed a major part of the research activity.

- Reviewing the results from Section 7.3, it is apparent that individuals can vary substantially in their exposure to odours
- Similarly, the reporting intensities of different groups based on health, age and employment pattern varied (see Section 7.2). This was anticipated to a certain extent by other research reviewed in Chapter 2. There were agreements with research findings, notably the lower reporting intensities produced by individuals with health problems, but there were also discrepancies. Smokers for example produced consistently higher reporting values than other groups and there was no significant differences observed in reporting patterns between males and females. This would not have been expected from the literature, although there are some disagreements between researchers (see Section 2.2). Such disagreements are perhaps a reflection of the difficulty of olfactometry testing which researchers sometimes refer to (see Sections 3.2 and 3.3). Undoubtedly, further work should be undertaken to clarify what the effects of such attributes on olfactory ability are.
- The results from the panel identified locations that are more or less likely to experience odour pollution notably landfill odour pollution

However the limitations of the panel and its results were extremely useful in providing insights into design, development and management of the monitoring panel. The limitations were identified as follows.

- The distribution of monitors across the Marston Vale, the numbers of monitors within different attribute groups and the size of the panel itself produced results which were not in keeping with what would have been anticipated from the literature
- Testing for the ability to discriminate odour pleasantness or unpleasantness was not undertaken. Odour hedonics could be an important factor in detection and annoyance levels. Therefore it is a recommendation that such testing, in the context of separate research, should take place to gain as much insight into odour impact as possible.

There are a number of clearly identified steps involved in the construction of an odour-monitoring panel. These can be divided into three categories.

Introduction of a panel:

- The first step involves ascertaining the extent of the impact of odour pollution. This could be done through use of a social survey in the local community in conjunction with the use of a dispersion model to identify areas likely to be affected by pollution.
- On the basis of the findings of the initial activity, the panel structure can be designed. Locations of monitors can be selected and the types of individual who would be required to make up the panel, according to the different response types demonstrated or implied by this research.
- Recruitment and training of prospective monitors should be undertaken. An important feature of this research has been the olfactory testing undertaken at the beginning of monitoring.

Panel design:

Secondly, the design and implementation of the odour monitoring panel itself. This would include a number of steps. A review of literature would enable researchers to identify individuals who may be more or less likely to detect odours. This was undertaken before the organisation of the panel for this research. The groups included gender, age groups, health and employment pattern. The findings of the panel were based on the attribute groupings.

Panels organised in the future can include the same groups, such as gender, health or working pattern identified in this research. There were areas where the results were inconclusive or contradictory. Once the use of a monitoring panel was decided upon the following steps should be taken.

- The size of the panel would be decided upon.
- Olfactory testing should be undertaken to identify individuals with problems with their sense of smell. This would include identification of anosmics and individuals that may attach unusual descriptions to odours. Similarly, information on aspects of the volunteers' background should be obtained.
- Consideration should be given to whether certain volunteers should be used, such as those with health problems.

Panel management:

- The monitors' reports should be produced in as uniform as possible.
- Recording monitors reports in a database to enable easy extraction of information of interest and to facilitate reliability checking.
- Monitors reports are then compared against wind direction and speed. The reports were also validated against each other using classifications of cloud and visibility. Report validation was important to identify monitors who could be introducing inaccuracies into the database.
- Periodic examination of monitors reports to identify individuals who could be suffering from monitoring fatigue or other sources of inconsistency. It should be remembered that new monitors appear to be likely to produce slightly higher levels of reports at the outset of monitoring and therefore time should be allowed for their reporting patterns to "settle". Similarly, long-term monitors can appear to experience monitoring "fatigue" whereby the numbers of their reports fall after a period of time. Therefore there should be a review of monitor performance over the long-term to identify monitors with this fatigue and remove them from the panel.

11.3 Collation of main activities and findings

The main activities consisted of the following,

- Use of a dispersion model, UK-ADMS. Such models can predict areas likely to be affected by pollutants and an overall number of hours odour will be present. However, as the focus of this research was "receptivity" or response to odour at the community level, the work with the model was sidelined (Section 4.3)
- Analysis of data from a social survey (1993) and pilot study data derived from an early monitoring panel (Sections 4.5, 5.2 and 5.4).
- Development of the odour monitoring tree, a conceptual tool which clarified the circumstances surrounding exposure to and detection of odour (section 5.3).
- These activities led to the development of the research question and objectives (Section 1.6), and the specific questions identified initially in Table 5.4 (and 11.1) (Section 5.2).
- Development and introduction of redesigned odour monitoring panel (Chapter 6)
- Analysis of monitoring panel data on the basis of individuals (Section 7.2), groups based on attributes (Section 7.3) and spatial and temporal factors (Chapter 8).
- Identification of how data reliability could be assessed (Chapter 9).
- Demonstration of how a population response framework could be developed (Chapter 10).

The findings of the research were as follows,

- There was substantial variation in reporting intensities on the level of the individual.
- There were no apparent similarities in reporting intensity levels in monitors with the same attribute, such as location, working pattern or age.

* Certain settlements, such as Stewartby, were identified as experiencing landfill odour more frequently than others. Similarly, reports were most common at particular times (8-9am, 2-4pm and –7pm).
* Hedonic properties were not as clear cut as in laboratory based experiments.

11.4 The contributions of the research

* The thesis develops the case that any assessment procedure examining the impact of pollutants must include all stages of the process of impact, from source and emission to dispersion to reception in an interdisciplinary method of assessment. It must also include data on the exposure levels of individuals in affected areas. The assumption that response is homogeneous across a community is incorrect. This receptivity within a community must be included in the assessment process if the extent of loss of amenity and costs to the operator are to be fully realised. This is illustrated in the detail from Figure 1.2 below.

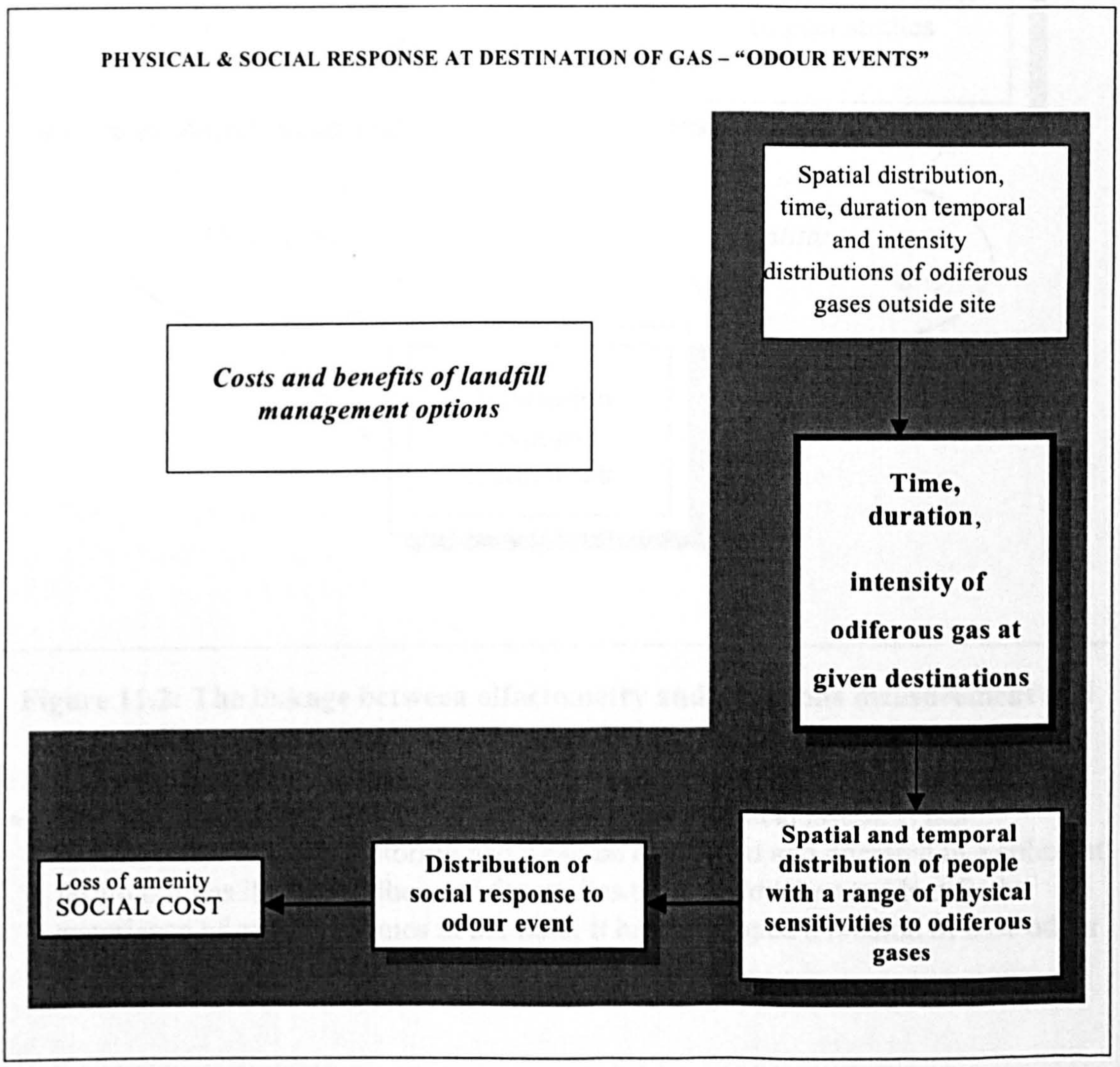


Figure 11.1: Detail of adapted model from Longhurst and Seaton (1999)

The demonstration of how estimating exposure of individuals or communities to a pollutant, such as odour, can be included in the assessment process by development of a population response framework. This model can indicate the extent of impact on members of communities or facilitate comparisons of impact between differing areas or settlements.

- That such a framework could provide a link between variability of response to odour demonstrated by olfactometry and the experience of odour in the general environment. It could be adapted for use in other studies relating to other pollutants, providing links between experimental data in the laboratory and exposure and response in the environment as illustrated in Figure 11.2.

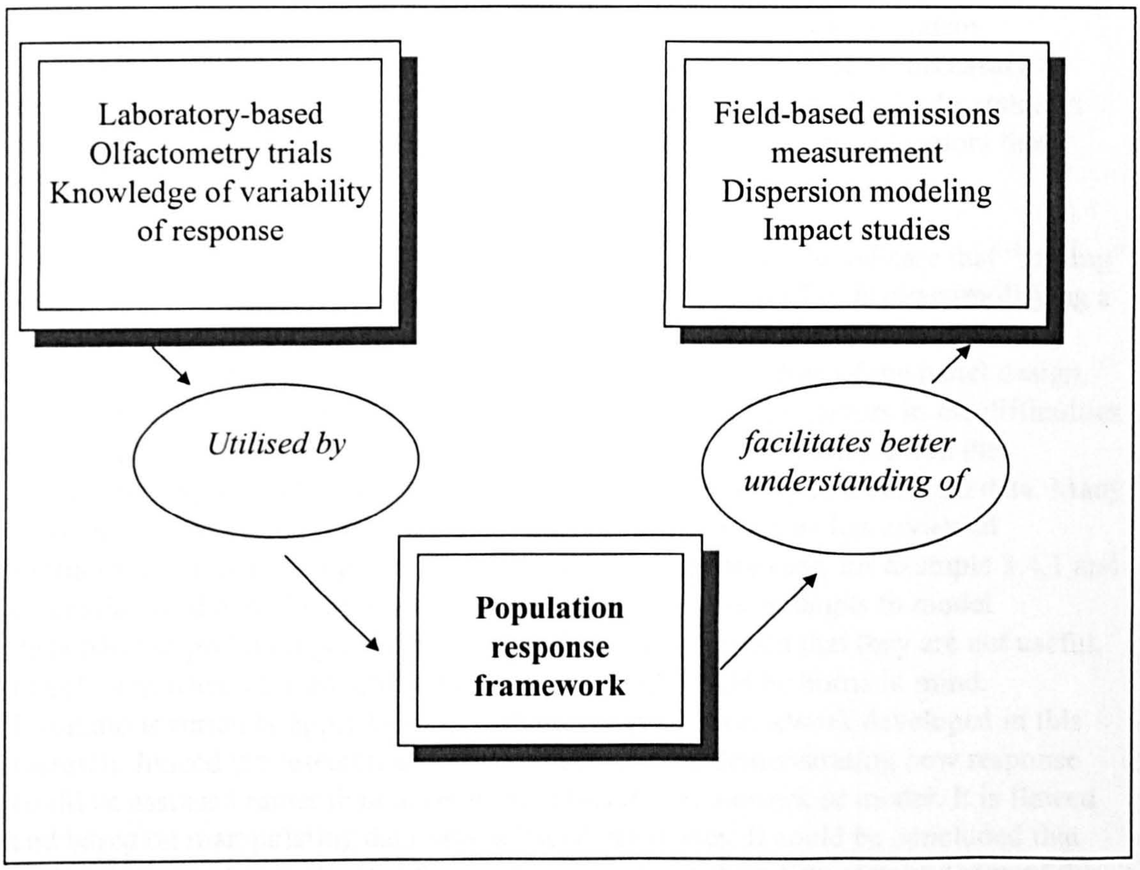


Figure 11.2: The linkage between olfactometry and emissions measurement and dispersion facilitated by the population response framework

- That the research has also addressed a number of technical issues. It has demonstrated how a monitoring panel can be developed and operated in a coherent fashion. It has illustrated the need for studies to be undertaken to identify the experience of odour hedonics in the field. It has developed a method of how odour dispersion, location and people can be linked together.

11.5 Comments on the development of a population response framework

Objective 1 stated that an attempt would be made to produce a community based population response framework. The panel used in the research can, in some ways, be seen as a means to an end to producing such a framework. It must be stressed that, while the framework could be developed and its uses identified, it is a basic instrument, with limitations. It was noted in Sections 7.2 and 10.1 that there was substantial variation in the detection levels of individuals on the monitoring panel. In the categories examined in Section 7.2, it became apparent that even within groups with the same attribute, such as health, age or employment pattern, there was immense richness in the variation of response. This is probably the case as a result of the ability to detect odour being a product of more than one attribute acting in tandem. Recognition of this interaction and an attempt to identify it would be necessary to develop a response model from the framework presented in this thesis. As stated in Section 10.1, this indicates further research into olfactory ability and factors that affect it will have to be undertaken.

As variability on the scale of the individual is so great, it would indicate that "forcing" individuals into attribute groupings, such as those in Section 7.3, is oversimplifying a complex phenomenon. It could be stated that such groupings are artificial and any data from attribute groups are extremely limited. The limitation of the panel design, its small size and the number of reports produced were major factors in the difficulties encountered with the development of the model. This would indicate that the population response framework is also limited, being developed from such data. Many models do have limitations, some more than others. This thesis has reviewed limitations of other attempts to model population response (see, for example 3.4.1 and discussion of the model produced by Clarenburg 1987) or attempts to model dispersion of pollution (see Section 3.3). This does not mean that they are not useful, merely that when they are utilised their limitations should be borne in mind. Limitations certainly apply to the population response framework developed in this research. Indeed the research activity could be seen as demonstrating how response could be assessed rather than developing a specific framework or model. It is flawed and based on manipulating data into artificial categories. It could be concluded that such a framework is so limited that, in fact a major contribution of knowledge of this thesis is that such an approach can not be attempted. In order to overcome these limitations, the panel from which data for model development would have to be much larger, more information on monitors known, and more rigorous testing of olfactory ability would be necessary. Indeed, identification of the effects of attributes on olfactory ability is vitally important before a community response model can be developed and adopted. This research did demonstrate that there may be discrepancies between the literature and what actually occurs in the real world, for example the results derived from males and females in the panel revealing no difference in the levels of response. Arguably, therefore a framework such as the one developed in this research is not a viable proposition and illustrates how not to attempt to model response! However this does not detract from the need for a model of some kind to be developed that could be used in interdisciplinary studies. Another means of tackling assessment of the response of a population to odour pollution could be adopted.

This research activity led to the realisation that there was a "knowledge gap" in the odour assessment process. This related to "receptivity". In order to obtain an estimate of odour impact on settlements and individuals, an interdisciplinary method using knowledge and techniques from all three areas should be combined. A thorough understanding of the source and physical environment, combined with instrument based methods, such as olfactometry and dispersion modeling, and a population response framework or potential model of some form would lead to a thorough understanding of impact.

11.6 Recommendations for further research

A central part of the research activity involved the development, introduction and management of an odour-monitoring panel. It was hoped to demonstrate the variation in exposure and response to odour throughout a community. The causes of this variation proposed as the personal attributes of individuals, such as their age, health, employment pattern and location. It was noted that during many odour impact studies, this variability is not taken into account, but that there is an assumption that exposure and response will remain the same across individuals and communities. Odour impact may be subtler in its effects, and require inclusion of data on community exposure. Below the recommendations from this research are highlighted.

- To undertake further research into how attributes identified in this thesis affect exposure and response to odour and how they interact. It was notable that, for example, gender did not seem to affect response levels, although much research stated that this should be the case. It is important therefore to identify what the influences of gender are on olfactory ability not only in the laboratory, where most research is undertaken, but also in the general environment, where odour pollution occurs.

- To refine and develop the monitoring system. As mentioned elsewhere in the thesis, there were a number of shortcomings identified with this procedure. For example, more detailed testing of olfactory ability to identify those individuals with idiosyncratic sense of smell. Screening individuals before monitoring to identify their opinions of odour sources involved in such studies so that they do not produce fictitious reports. The use of local weather data collected in a similar environment to where monitors live to ensure that validation of reports is carried out on a more satisfactory basis (see Sections 9.2, 9.6 and 9.8) .

- Planners and regulators dealing with landfill sites could use an interdisciplinary method of odour assessment in order to address the problem of assessing odour nuisance, as well as a guide to predicting impact in planning applications pertaining to landfills.

- Attempts to model individual and community response could be made in other areas of pollution assessment. Opportunities for further research could be developed to consider the combined social and epidemiological impacts of other pollutants.

- Attempts to model individual and community response could be made in other areas of pollution assessment. Opportunities for further research could be developed to consider the combined social and epidemiological impacts of other pollutants.

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Appendix A

Guidance notes for monitors

Pre-monitoring Questionnaire

Time Diary

Post-monitoring Questionnaire

Guidance notes for odour monitors

Thank-you for volunteering as an odour monitor for IERC.

These notes have been produced to help you monitor successfully and avoid any problems you may have. If, when you have read these notes you are still uncertain about what to do, contact either Suzanne Hitchin or Phil Longhurst at IERC straightaway. The phone number is 01234 750111 extensions 2658 or 2013. You can write to us care of IERC, Cranfield University, Cranfield, Bedford, MK43 0AL.

Do not worry about providing 'right' or 'wrong' answers! Simply do you best!

Contents

1. Materials you need.

When you start monitoring, you will be provided with the following,

Forms to record you reports on

Reply-paid envelopes

If you do not have any of these things or if you run out of them, contact us straight away. We will send out what you need. Usually, we will send out new forms and envelopes to you every month or so,

2. Getting started.

Firstly, look at you record sheet and familiarise yourself with the information you have to record. Then you follow the following steps.

Once a day, at your regular time, go out and sniff the air. If you smell an odour at any other time, *report that odour as well.* A space is provided on your record sheet for a second report. There is room in the margin to write details of a third odour if you happen to smell one.

If you cannot or forget to monitor at your usual time on a particular day, monitor when you remember. If you miss a day or several days, simply record the date on the sheet and write below it 'forgot to monitor'. Do not make up a report! (See section 3 below about missing reports.)

<u>If you detect odour</u>

Take your record sheet and complete the questions in the list as follows.

1. Fill out the date on your record sheet.

2. Fill out your location. When you do your daily sniff, you'll obviously be outside at home. If you are reporting an odour at any other time, you record if you are inside or outside a building and where you are, for example at home, at the shops or at the bus stop. If you were not at home, please provide an address or description of where you smelled the odour. Remember, we do not know where your local shops, school and bus stops are!

3. On the activity line, fill out what you were doing at the time when you smelled the odour. You may have been doing your odour monitoring at your set time. In this case you write 'monitoring'. On the other hand you may have noticed the odour at another time, when you were not monitoring, for example when you were doing housework, watching television, gardening, shopping or doing nothing in particular!

4. Fill out the time when you sniffed for odour or when you smelled the odour.

5. *If you can*, record the length of time you could smell the odour. Do not worry if you cannot do this. You may have to leave, to go to work for example, or you may become used to the odour and not be able to smell it.

6. Estimate the amount of sky covered by cloud. A list is shown below of different types of cloud cover. Select the code number that you think best describes the type of cover you see and write it on your record sheet.

clear sky - no clouds............code 1	dark rain clouds............code 5
high / light clouds................code 2	misty / haze...................code 6
separate white clouds..........code 3	fog................................code 7

dull / overcast......................code 4 fog / drizzle...................code 8

7. Record, *if you can,* what you think the source of the odour is. The code numbers for odours are

Code number

1	Local odours, e.g. bonfires, traffic fumes, local industry.
2	Landfill odours
3	Brickworks odours
4	Agricultural odours, e.g. spreading fertiliser, crop odours.

Some odours may be unmistakable, others may not be so easy to identify. Do not worry about not being able to say what the odour is. If you really have no idea, do not guess.

8. If you think you know what the odour is, say how certain you think you are. If you are very certain, give a score of 1. If you are a little unsure, give the certainty a score of 2 and if you are not very sure give a score of 3.

9. Record how pleasant the odour is on the scale of 1 to 7. Simply circle or tick the suitable number on the line. A score of 1 means the odour is pleasant, a score of 7 means the odour is extremely unpleasant!

10. Record how intense or strong you think the odour is. Again circle the appropriate number on the line. A score of 1 means the odour is very weak, a score of 7 means the odour is very strong.

11. If you want to record something about the odour that is not covered by the questions above, use the 'Any comments' line. For example, you may want to describe how the odour smells to you, if the strength of the odour changed or if the odour lingered for some time. You may want to say something about when or where you smelled the odour, for example something about the weather conditions.

If doing this takes you longer than around 5 or 10 minutes, you are taking too long! Please do not let it disrupt your usual routine too much.

<u>If you do not smell odour.</u>

Take your record sheet and complete questions 1, 2, 3, 4, and 6, following the instructions in the section above. Leave the other spaces blank.

Do not worry if you smell odours very frequently or do not smell odour very often. People vary in the odours they can smell and when they smell them.

3. What to do if you do not or cannot fill in your record sheet!

We understand that you will not always be able to monitor. You may be ill, on holiday or you may just forget. Do not worry about this!
Simply fill out the date in the right space on your record sheet and write ill, on holiday, out all day, forgot to monitor or what ever the reason was, below it.

DO NOT MAKE UP A REPORT!

If you do make up a report, it will affect the information we have to work with.
We will pay you as usual, you will not be deducted money for missed reports.

4. What to do with your completed record sheets.

Once a month, send in your record sheets in the envelopes provided. You do not have to pay postage. Just pop the envelope into a post-box. Try to send in you record sheets regularly, otherwise you will be snowed under with lots of paper!

5. What to do if you want to stop monitoring

We appreciate the commitment of odour monitors and understand if monitoring becomes inconvenient. If you want to stop, tell us when you can. If possible try to complete your last month of monitoring, as we deal with monitors' information on a monthly basis. We will arrange for your pay to made up to when you stop monitoring.

Finally, the important bit....

6. What about the money!

You will be paid £23, excluding deductions, for every month you monitor. The cheques will be sent out to you on a monthly basis.

If you do not receive your cheque, please contact us so we can chase up your payment.

As we said earlier, if you have any queries or problems, please contact us straightaway!
Happy monitoring!

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For use by IERC Staff only.

There are a number of factors that are known to affect a person's sense of smell. If you are selected as a monitor, we will need to know which of these factors, if any, may influence your odour reports. Therefore, please complete the following questionnaire, which deals with these factors.

Answer all questions, either by ticking the boxes or by brief answers.

Name...
Address...
....
Telephone..

Smoking

1. Do you smoke? Yes ☐ No ☐
2. If you have given up smoking, how long ago was this?..........................
3. Does anyone else in your home smoke? Yes ☐ No ☐
4. Are you exposed to smoking elsewhere, for example in your work place?
   Yes ☐ No ☐

Health

5. What is your age?

18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ 65+ ☐

6. Do you have any medical condition that may influence your sense of smell?
   For example sinus problems, asthma, allergies and hay-fever, pregnancy.
   Yes ☐ No ☐

Occupation

		please tick
7. Are you	employed full-time?	☐
	employed part-time	☐
	unemployed	☐
	full-time student	☐
	housewife/carer	☐
	retired	☐

Please state, if you are employed what your job is...

8. Are you exposed during your daily routine/employment to gases, vapours, particulates/dust? For example, solvents, wood dust, oil-based products such as petrol, polishes.
   Yes ☐ No ☐

<u>The pre-monitoring questionnaire</u>

9. If your answer was 'yes' to question 9, please state what these materials are ....

10. In your opinion, is your exposure to these materials greater than average?
Yes ☐ No ☐

Times available for monitoring
Please tick which hours of the day you will usually be available for monitoring.

5 to 6am	☐	12 to 1pm	☐	7 to 8pm	☐
6 to7am	☐	1 to 2pm	☐	8 to 9pm	☐
7 to 8am	☐	2 to 3pm	☐	9 to 10pm	☐
8 to 9am	☐	3 to 4pm	☐	10 to 11pm	☐
9 to 10am	☐	4 to 5pm	☐	11pm to 12am	☐
10 to 11 am	☐	5 to 6pm	☐		
11am to 12 pm	☐	6 to 7pm	☐		

Living in the Marston Vale

12. How long have you lived in this area?..

13. Please list the things you enjoy about this area
1. ....
2. ....
3. ....

14. Please list the things you least enjoy about this area
1. ....
2. ....
3. ....

All the above information will be treated in strictest confidence and will be retained within IERC. This questionnaire does not constitute a health screening test.

THANK-YOU FOR YOUR CO-OPERATION.

We would like to know how often you may be exposed to odour at you home. Therefore for one week, we would like you to note the following details.

1. Times you get up and go to bed.
2. Any times you leave and return home. If you leave and return home more than once a day, then record all these times. If you do not leave home during the day, just record the times you got up and went to bed. If you forget to note the times, please make an estimate.

Name.................................. Address...

Day 1. Date..........................
Time got up...........................
Time left home....................... ....
Time returned home................ ....
Time went to bed...................

Day 2. Date...........................
Time got up............................
Time left home....................... ....
Time returned home.............. ....
Time went to bed....................

Day 3 Date..............................
Time got up.............................
Time left home........................ ....
Time returned home................ ....
Time went to bed....................

Day 4. Date............................
Time got up.............................
Time left home........................ ....
Time returned home................ ....
Time went to bed.....................

Day 5. Date............................
Time got up.............................
Time left home........................ ....
Time returned home................ ....
Time went to bed.....................

Day 6. Date............................
Time got up.............................
Time left home........................ ....
Time returned home................ ....
Time went to bed.....................

Day 7. Date.............................
Time got up..............................
Time left home......................... ....
Time returned home................. ....

The monitor time diary

A monitor report sheet

Name.. Address..

	First Report	Second Report
1. Date....................................		
2. Location..		....
3. Activity..		....
....		....
4. Time..		....
5. Length of time of odour (if known)............		....
6. Cloud cover..		....
7. Odour source (if known)............................		....
8. Certainty..		....
9. Pleasantness	1 2 3 4 5 6 7	1 2 3 4 5 6 7
10. Intensity	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Any comments..		....
....		....
....		....
1. Date....................................		
2. Location..		....
3. Activity..		....
....		....
4. Time		....
5. Length of time of odour (if known)............		....
6. Cloud type..		....
7. Odour source (if known)............................		....
8. Certainty..		....
9. Pleasantness	1 2 3 4 5 6 7	1 2 3 4 5 6 7
10. Intensity	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Any comments..		....
....		....
....		....

The Post-monitoring Questionnaire

For use by IERC Staff only

As you have now completed monitoring for IERC, would you please complete this questionnaire. It contains questions that could not be asked before or during monitoring, but will help with analysing the results.
As in the previous questionnaire, please answer all the questions either by ticking boxes or by brief answers.

Name..

Monitoring

1. How easy did you find monitoring for IERC?

Very easy ☐ Not easy, but not difficult ☐ Difficult ☐
Easy ☐ Very Difficult ☐

2. What problems did you have, if any? For example was it too inconvenient, did you keep forgetting?

....
....
....

3. Were you given sufficient information and support during the monitoring period?

....
....

4. Why did you volunteer for air quality monitoring for IERC? For example was it because you are interested in, or concerned about the environment?

....
....
....
....

Your Daily Reports

5. Did you find you reported odours in general more or less often than what you expected you would?

More often ☐ About what you expected ☐ Less often ☐

6. Did you find that you reported particular types of odours more or less often that what you had expected you would?

More often ☐ About what you expected ☐ Less often ☐

7. Which odour types did you feel you recorded more or less than you expected?

Odour type	More or less often?	
Local	more often ☐	less often ☐
Landfill	more often ☐	less often ☐
Brickwork	more often ☐	less often ☐
Agricultural	more often ☐	less often ☐

8. Were you surprised by the results you recorded?

....

....

9. Do you feel that you are more or less aware of odour now you have taken part in the study?

more aware ❑ less aware ❑ about the same ❑

You and your environment

10. Have you ever complained to any organisation about any kind of nuisance from any source? For example noise, traffic, dust, odours or new development.

Yes ❑ No ❑

11. If the answer is yes, what was it you complained about?

....

....

12. Who did you complain to?

The person / company responsible for the odour source	❑
The local council	❑
A local councillor	❑
A pressure group	❑
Other	❑

13. When you have smelled odours, have you ever done any of the following?

If you were outdoors, gone indoors?	❑
Closed windows?	❑
Used air fresheners?	❑
Tried not to breathe to deeply?	❑
Taken any other action?	❑

If you have taken any other action please specify what this was

....

14. Have you ever experienced any of the following due to odour?

Headaches	❑	Tummy upsets	❑
Annoyance	❑	Irritability	❑
Nausea	❑	Respiratory problems	❑
Appetite loss	❑	Other	❑
		Please specify........................	

15. Are there any other comments you would like to make about the monitoring and its results, or about living in the Marston Vale?

....

....

....

....

....

Thank-you for completing this questionnaire.

Thank-you for taking part in the air quality monitoring project.